Ranking the Risks: The 10 PaThogen-Food CombinaTions WiTh The greaTesT burden on PubliC healTh

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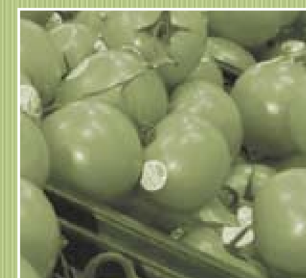

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Support for this report was provided by a grant from the Robert Wood Johnson Foundation.

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TABLE OF CONTENTS

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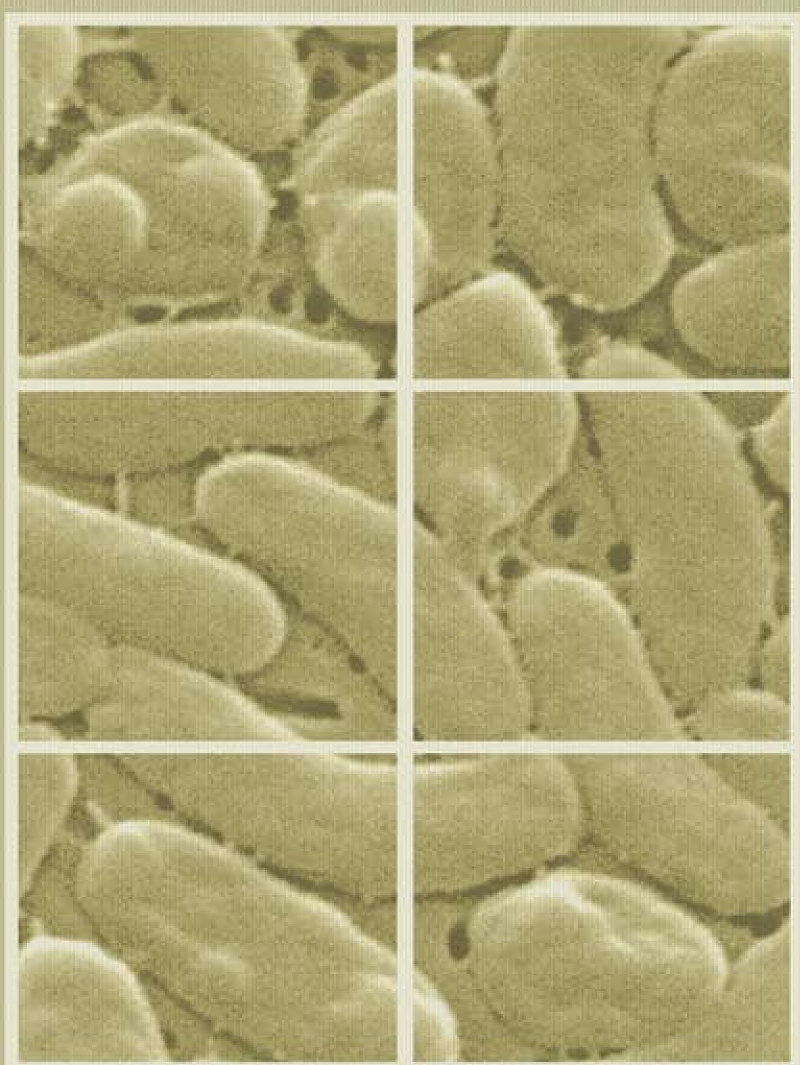
ABBREVIATIONS AND ACRONYMS

CSPI	Center for Science in the Public Interest
CDC	Centers for Disease Control and Prevention
CFSAN	Center for Food Safety and Applied Nutrition (FDA)
COI	Cost of Illness
DALY	Disability Adjusted Life-Year
EQ-5D	EuroQol
ERS	Economic Research Service (USDA)
ESRD	End Stage Renal Disease
FDA	U.S. Food and Drug Administration
FIRRM	Foodborne Illness Risk Ranking Model
FoodNet	Foodborne Diseases Active Surveillance Network
FSIS	Food Safety and Inspection Service (USDA)
FSMA	Food Safety Modernization Act
FSRC	Food Safety Research Consortium
GAO	U.S. Government Accountability Office
GBS	Guillain-Barré Syndrome
HALY	Health Adjusted Life Year
HPA	Health Protection Agency Centre for Infections (United Kingdom)
HRQL	Health-Related Quality of Life
HUS	Hemolytic Uremic Syndrome
IFSAC	Interagency Food Safety Analytics Collaboration (CDC, FDA, USDA)
IOM	Institute of Medicine
MMWR	Morbidity and Mortality Weekly Report (CDC)
NAS	National Academies of Science
NIS	Nationwide Inpatient Sample
OMB	Office of Management and Budget
Outbreak Net	Outbreak Network for Foodborne Diseases Surveillance and Response (CDC)
PulseNet	National Molecular Subtyping Network for Foodborne Disease Surveillance (CDC)
QALY	Quality Adjusted Life-Year
RIVM	National Institute for Public Health and the Environment (Netherlands)
RWJF	Robert Wood Johnson Foundation
STEC	Shiga-toxin producing *E. coli*
S.T.O.P.	Safe Tables Our Priority
USDA	U.S. Department of Agriculture
VSL	Value of Statistical Life

Executive Summary



EXECUTIVE SUMMARY

On January 4, 2011, President Obama signed into law the most far-reaching food safety legislation in over 70 years. The Food Safety Modernization Act (FSMA) mandates a science- and risk-based system built upon the premise that data-driven analysis should inform the efficient targeting of efforts to minimize foodborne illness risks to the American consumer. The National Academy of Sciences (NAS), the U.S. Government Accountability Office (GAO) and others have repeatedly called on the U.S. Food and Drug Administration (FDA) and the Food Safety and Inspection Service of the U.S. Department of Agriculture (USDA FSIS) to become more preventative and risk-based. Achieving this vision will require development of new data and risk-prioritization models to identify high-risk foods and facilities and to inform resource allocation decisions. Tightening budgets make implementation of this vision all the more urgent.

The starting point for implementing risk-based food safety systems is being able to identify where the greatest food safety problems lie. For foodborne illness, the starting point is the question: which pathogens in *which foods cause the greatest impact on public health*?

The question is easy to ask. Getting a good answer isn't. The U.S. Centers for Disease Control and Prevention (CDC) estimates that one in six Americans get sick each year from food contaminated by any one of dozens of bacteria, viruses and parasitic protozoa (Scallan et al. 2011a, 2011b). Foodborne pathogens cause not only mild diarrhea, but organ failure, paralysis, neurological impairment, blindness, stillbirths and death. Risk-based prioritization requires having some way to summarize the burden of these diverse conditions into comparable measures of health impact. Furthermore, these illnesses are associated with myriad foods, from poultry to produce to peanut butter, but estimating the association between particular foods and these issues is not straightforward.

To provide a means of comparing the risks posed by different pathogen food combinations in the U.S., we developed a comparable set of estimates of disease burden for 14 leading pathogens across 12 food categories (168 pathogen-food combinations). These fourteen 14 pathogens represent over 95 percent of the annual illnesses and hospitalizations, and almost 98 percent of the deaths, estimated by CDC due to 31 foodborne pathogens (Scallan et al. 2011a). For each pathogen, we estimate health impacts in monetary cost of illness and loss of Quality Adjusted Life Years (QALYs), a measure of health-related quality of life. Both cost of illness and QALY loss are integrated measures of disease burden that allow us to compare pathogens with very different rates of incidence, hospitalization and death, as well as different symptoms and long-term chronic conditions. We attribute these illnesses to foods based on an analysis of eleven years of foodborne outbreak data and a peer-reviewed expert elicitation (Hoffmann et al. 2007). We explain our method in Chapter 2. There are significant uncertainties in the data sources and model assumptions used to obtain our estimates, and therefore in the estimates themselves. Our analysis is constrained by these limitations. Our estimates should be regarded, therefore, as an important starting point in an ongoing process to improve our understanding of the very complex interactions among pathogens and foods in the U.S. food system.

Rankings

By Pathogen

We estimate that 14 foodborne pathogens cause 14.1 billion (2009 dollars) in cost of illness[1], and loss of over 61,000 QALYs per year. More than 90 percent of this health burden is caused by five pathogens: *Salmonella* spp.[2], *Campylobacter* spp., *Listeria monocytogenes*, *Toxoplasma gondii* and norovirus. Table ES-1 presents the public health impact of all 14 foodborne pathogens, according to five measures of disease burden: annual QALY loss, cost of illness, number of illnesses, hospitalizations and deaths. Pathogens are ordered by averaging their rank in QALY loss and their rank in monetary impact.

Table ES-1: Annual Disease Burden Caused by 14 Foodborne Pathogens

Pathogen	Combined Rank*	QALY loss	Cost of Illness ($ mil.)	Illnesses#	Hospital-izations#	Deaths#
Salmonella spp.	1	16,782	3,309	1,027,561	19,336	378
Toxoplasma gondii	2	10,964	2,973	86,686	4,428	327
Campylobacter spp.	3	13,256	1,747	845,024	8,463	76
Listeria monocytogenes	3	9,651	2,655	1,591	1,455	255
Norovirus	5	5,023	2,002	5,461,731	14,663	149
E.coli 0157:H7	6	1,565	272	63,153	2,138	20
Clostridium perfringens	6	875	309	965,958	438	26
Yersinia enterocolitica	8	1,415	252	97,656	533	29
Vibrio vulnificus	8	557	291	96	93	36
Shigella spp.	10	545	121	131,254	1,456	10
Vibrio other+	11	341	47	57,616	210	4
Cryptosporidium parvum	12	149	107	52,228	183	12
E.coli non-O157 STEC	13	327	26	112,752	271	0
Cyclospora cayetanensis	14	10	2	11,407	11	0
Total		**61,461**	**14,114**	**8,914,713**	**53,678**	**1,322**

* Combined rank is the rank order when QALY rank and COI rank are averaged
# Incidence estimates are mean estimates reported in Scallan et al. (2011a).
+ includes *Vibrio parahaemolyticus* and other non-choleric *Vibrio* species

1 Unless otherwise noted, all values are in 2009 dollars
2 Here and throughout the text, Salmonella spp. refers to nontyphoidal serotypes.

By Pathogen-Food Pair

A limited number of pathogen-food combinations are estimated to be responsible for most of the foodborne illness caused by the 14 pathogens included in this study. The top 50 pathogen-food combinations account for more than 90 percent of illnesses, hospitalizations and deaths examined in this study. The top 10 pathogen-food combinations are responsible for over $8 billion in costs of illness annually or nearly 37,000 lost QALYs, reflecting almost 60 percent of the impacts estimated across all 168 combinations. These top 10 pathogen-food combinations are shown in Table ES-2, ordered by their combined (average) rank in QALY impacts and cost of illness impacts.

Table ES-2: The top 10 pathogen-food combinations in terms of annual disease burden, by combined rank

Pathogen-Food Combinations	Combined Rank	QALY loss	Cost of Illness ($ mil.)	Illnesses	Hospital-izations	Deaths
Campylobacter – Poultry	1	9,541	1,257	608,231	6,091	55
Toxoplasma – Pork	2	4,495	1,219	35,537	1,815	134
Listeria – Deli Meats	3	3,948	1,086	651	595	104
Salmonella – Poultry	4	3,610	712	221,045	4,159	81
Listeria – Dairy products	5	2,632	724	434	397	70
Salmonella – Complex foods	6	3,195	630	195,655	3,682	72
Norovirus – Complex foods	6	2,294	914	2,494,222	6,696	68
Salmonella – Produce	8	2,781	548	170,264	3,204	63
Toxoplasma – Beef	8	2,541	689	20,086	1,026	76
Salmonella – Eggs	10	1,878	370	115,003	2,164	42
Total		**36,915**	**8,151**	**3,861,128**	**29,830**	**765**

Campylobacter in poultry is ranked first in both QALYs and dollars. While *Campyolobacter* is only the third (tied) ranked pathogen overall, these impacts are estimated to be primarily focused in a single food commodity, based on our expert elicitation.

Toxoplasma gondii is not a "front page" foodborne pathogen, but it is very important from a public health standpoint. CDC estimates that foodborne toxoplasmosis causes 327 deaths annually, second only to *Salmonella* (Scallan et al. 2011a); this high rate of mortality drives its ranking in our cost of illness and QALY rankings. Although conventionally associated with handling of cats and kitty litter, CDC now estimates that 50 percent of toxoplasmosis is foodborne. *Toxoplasma* is known to be associated with consumption and handling of raw or undercooked meats and raw goat's milk, but attribution data is uncertain. Based on an expert elicitation conducted by Hoffmann et al., (2007), pork (2nd) and beef (tied for 8th) are the highest ranking food commodities, but other data, including a recent FoodNet case-control study (Jones et al. 2009), suggests this estimate of attribution to pork may be overstated.

Listeria monocytogenes in deli meat (3rd) continues to be a major concern, though there have been major gains over the last decade in reducing contamination rates of packaged deli meats (USDA 2010). FSIS and others have found, however, that the risks associated with retail-sliced deli meats to be five times higher than for prepackaged deli meats (Gombas et al. 2003, Endrikat et al. 2010). The ranking of *Listeria* in dairy products (5th) is driven by a number of outbreaks associated with soft ripened cheeses made from unpasteurized milk, particularly queso fresco, a traditional fresh cheese common in Mexican cuisine (Voetsch et al. 2007).

Although *Salmonella* has the greatest health burden as measured by both cost of illness and QALY loss, that burden is distributed across a wide range of food products. *Salmonella* appears four times in the rankings, with the most significant burden of disease associated with poultry (4th). The other three food categories are non-meats. Salmonellosis due to contaminated produce (tied for 8th) has been recognized by others as a growing problem (Lynch et al. 2009, Maki 2009). In an analysis of foodborne outbreaks from 1998 to 2008, we found that of those due to *Salmonella* in produce, more than half were associated with tomatoes, sprouts or cantaloupes.[3] *Salmonella* in eggs (10th) remains a major concern, though risks have significantly declined over the last twenty years (Braden 2006).

Salmonella and norovirus are both highly associated with "complex foods" (tied for 6th), a category created to capture outbreaks associated with non-meat dishes comprised of multiple ingredients, and for which a specific contaminated ingredient could not be identified. The nature of these outbreaks suggests an important role for contamination, cross-contamination, and other mistakes during handling, preparation, and cooking. The role of food workers has long been understood as a critical factor in outbreaks (Greig et al. 2007). It has been suggested that up to 70 percent of foodborne illness are acquired outside the home (Chapman et al. 2010). In our analysis of complex food outbreaks between 1998 and 2008, more than 70 percent of those due to *Salmonella* and 80 percent of those due to norovirus were prepared in professional kitchens.

It is important to recognize that these rankings reflect disease burden of the population of the United States for one year, and do not reflect risks to individual consumers or risk per serving. Susceptibility to illness from a particular pathogen depends on age, gender, and underlying health; for example, middle-aged men with liver disease are particularly susceptible to *Vibrio vulnificus*. Likewise, annual risk is a function of risk per serving and the number of servings consumed. Some of the riskiest foods on a per serving basis are consumed quite rarely, while some of the safest foods are consumed often enough and in large enough quantities to cause significant disease burden.

By Foods

The results of food rankings are shown in Table ES-3. Poultry ranks first causing over $2.4 billion in estimated costs of illness annually and loss of 15,000 QALY a year. Pork and complex foods tie for 2nd, though pork's ranking may be too high, as the estimates are driven by attribution estimates for *Toxoplasma gondii* that may be outdated. It is notable that that produce is estimated to cause greater QALY loss and cost of illness than beef.

3 This is true even when accounting for the recent acknowledgment by investigators that the 2008 *Salmonella* Saintpaul outbreak was caused by contaminated peppers and not tomatoes (Behravesh et al. 2011)

Table ES-3: Disease Burden by Food Category, Summed Across Pathogens, by Combined Rank

	Food Category	QALY Loss	Cost of illness ($ mil.)	Illnesses	Hospital-izations	Deaths
1	Poultry	14,744	2,462	1,538,468	11,952	180
2	Complex foods	7,518	2,078	3,001,858	11,674	189
3	Pork	7,830	1,894	449,322	4,334	201
4	Produce	6,171	1,404	1,193,970	7,125	134
5	Beef	5,766	1,338	760,799	4,818	131
6	Deli/Other Meats	5,065	1,338	204,293	1,889	129
7	Dairy products	5,410	1,232	297,410	2,933	114
8	Seafood	2,762	921	642,860	2,937	97
9	Game	2,551	651	46,636	1,106	69
10	Eggs	2,252	428	170,123	2,472	45
11	Baked goods	988	273	462,399	1,833	25
12	Beverages	403	94	146,577	606	8
	Total	**61,461**	**14,114**	**8,914,713**	**53,678**	**1,322**

Foods associated with numerous pathogens (poultry, pork, produce) rank much higher than those ordinarily associated with only one or two pathogens (eggs, seafood). Analysis by foods highlights why use of multiple empirical measures is necessary to understand the complex picture that is arguably oversimplified by top 10 lists. For example, although *Salmonella* in eggs ranks within the top 10 pathogen-food pairs, eggs are estimated to be among the lowest ranking food categories overall. This is because few other pathogens have high numbers of egg-associated illnesses, hospitalizations or deaths.

An important feature of risk-based decision making is taking seriously the uncertainty inherent in any analysis of empirical data. The tables above, it must be noted, are based on point values and one set of modeling assumptions. There are significant uncertainties underlying the data and assumptions upon which our model is built, and therefore of our results. Sensitivity analyses that consider uncertainty in incidence estimates, health valuation estimates and attribution data and assumptions are summarized in Chapter 3, and further analyses are underway. The estimates presented in the above tables should be regarded, therefore, as a starting point in an ongoing process to improve data sources and better understand the very complex interactions among pathogens and food in the U.S. food system.

FINDINGS AND RECOMMENDATIONS

We identify nine major findings, presented in detail in Chapter 4 and summarized here:

1. **The public health burden of 14 foodborne pathogens in the United States to be over $14 billion or 60,000 QALYs per year, with 90 percent of these impacts due to only five pathogens: *Salmonella*, *Campylobacter*, *Listeria*, *Toxoplasma* and norovirus.** The 14 pathogens analyzed represent over 95 percent of the annual illnesses and hospitalizations, and almost 98 percent of the deaths, due to the 31 specific foodborne pathogens estimated by CDC. Long-term complications resulting from acute infection are an important component of disease burden estimates for *Campylobacter*, *Listeria*, and *Toxoplasma*. Across all 14 pathogens in all foods, we find about 60 percent of the burden is due to only 10 pathogen-food pairs, a list which includes a variety of commodities including poultry, pork, produce, beef, dairy products and eggs.

2. **Consumption of FDA-regulated foods is estimated to cause about half of the overall national burden of foodborne disease.** Although attribution data are imperfect, our analysis suggests that poultry, pork and beef (all regulated by USDA) cause about $5.7 billion or loss of 30,000 QALYs in disease burden annually, while produce, dairy products, seafood, breads, beverages and multi-ingredient complex foods (e.g. non-meat dishes served in restaurants, other establishments or homes, as well as processed foods such as peanut butter) cause about $6.0 billion or 24,000 QALYs in disease burden. Deli meats and eggs cause an additional $1.8 billion or loss of 7,000 QALYs. This can be viewed as a shared USDA/FDA responsibility; although FSIS regulates deli meat manufacture and processing, FDA has federal responsibility for developing model statutes for food handling in food service and retail food establishment where contamination often occurs. It is important to note that our estimates of the burden of disease take current control efforts in the private and public sectors as given. These estimates do not measure the efficacy of either FSIS or FDA activities.

3. **Four of the top 10 pathogen-food combinations represent significant risks to pregnant women and developing fetuses.** Congenital listeriosis and toxoplasmosis can both lead to miscarriage, stillbirth and neonatal death, as well as lifelong complications ranging from mild learning disabilities to severe mental impairment, permanently blurry vision, neurological disorders, and paralysis. Our analysis suggests that current efforts at reducing these risks may not be sufficient, particularly with respect to *Listeria monocytogenes* in deli meats and in dairy products (such as queso fresco made and consumed in Latino communities from raw milk), and *Toxoplasma gondii* in pork, beef and other meats. Increased efforts, such as targeted educational campaigns, may be warranted.

4. ***Salmonella* causes more disease burden than any other foodborne pathogen, and according to FoodNet surveillance data, is one of the few foodborne pathogens that has not significantly declined over the past 10 years.** According to CDC estimates, *Salmonella* is the leading pathogen in terms of annual deaths and hospitalizations. Our analysis suggests it is also the leading pathogen whether measured in cost of illness ($3.3 billion) or in impacts to health-related quality of life (loss of 17,000 QALYs). Our analysis also shows *Salmonella* disease burden as being associated with a wide variety of foods regulated by both FSIS and FDA, with significant risks associated with poultry, produce and eggs. This suggests that reduction of the national burden of salmonellosis will require a coordinated effort by both agencies addressing a broad array of foods. We recommend the agencies convene a national cross-agency initiative in collaboration with CDC that looks across the entire food system to target opportunities for risk reduction.

5. **Contaminated poultry has the greatest public health impact among foods. It is responsible for an estimated $2.5 billion or loss of 15,000 QALYs in annual disease burden.** Poultry is the only food commodity (e.g. other than complex dishes) that appears twice in our top 10. Its most significant disease burden is due to contamination with *Campylobacter* and *Salmonella*. Our analysis supports FSIS decisions in 2010 to increase the stringency of *Salmonella* performance standards in broiler chickens for the first time in 15 years and to set new performance standards for *Campylobacter* for the first time in the agency's history (USDA 2009, 2011). Ongoing improvement in this area is necessary, however. Dynamic performance standards would allow such efforts to be brought into an environment of continual improvement.

6. **Considerable burden of disease is caused by food handling and preparation problems in food service and retail settings.** The role of food workers has long been understood as an important factor in foodborne disease. *Listeria monocytogenes* in deli meats ranks as the pathogen-food pair with the third highest disease burden, and recent studies suggest that the majority of these illnesses are due to retail-sliced deli meats rather than those that are prepackaged. Likewise, FoodNet case control studies for numerous pathogens consistently show higher risks for foods prepared outside the home. In our analysis, complex multi-ingredient dishes, often prepared by restaurants, caterers, cafeterias, deli counters and other establishments, are the third leading food group in terms of associated burden of disease. Depending on the pathogen, 70-80 percent of outbreaks in our dataset due to complex foods were caused by foods prepared outside of the home. This suggests that there remains room for significant improvement in food safety in professional kitchens, both through private sector efforts to facilitate a culture of food safety, and through the strengthening of the critical efforts of state and local public health and regulatory agencies that oversee these establishments. Government actions that could improve retail and food service food safety include fully funding state and local inspection activities, increasing adoption of the most recent FDA Food Code by states, increasing the risk-basis of inspection criteria, and increasing education and training of food workers and government inspectors.

7. ***Toxoplasma gondii* causes disease burden of nearly $3 billion or 11,000 in QALY loss, yet our understanding of the pathways for human infection from *Toxoplasma* is limited.** Although toxoplasmosis is conventionally associated with cats and kitty litter, CDC now estimates that 50% of cases are foodborne (Scallan et al. 2011a). CDC also estimates that foodborne toxoplasmosis is surpassed only by *Salmonella* in the number of annual deaths it causes (Scallan et al. 2011a). Attribution data linking illnesses to specific foods is lacking, however, hindering the ability of the government to intervene effectively to prevent these illnesses. *Toxoplasma* has historically been associated with pork, but tests on pork show a major decline over the last 15 years, while a recent case-control study by CDC found the leading foodborne risks to be eating raw ground beef, rare lamb or locally-produced cured, dried or smoked meat (Jones et al. 2009). Improved surveillance is needed to better estimate the true incidence of foodborne toxoplasmosis, and significant increases in data collection, epidemiologic studies and scientific research are needed to understand the relative importance of routes of toxoplasmosis transmission. This effort needs to involve both regulatory and research agencies in the federal government as well as researchers in universities and the private sector.

8. ***E. coli* O157:H7 and non-O157 STECs cause about $300 million or loss of 2,000 QALYs in disease burden annually.** Although the overall burden of disease is not as high as the top five pathogens, individual cases of illness are devastating both physically and financially, and often occur in small children, a sensitive subpopulation that warrants particular protection. Our findings do not suggest that STECs are unimportant or that special attention to *E. coli* O157:H7 is unwarranted; rather, the lesson should be that there are other pathogens with less public awareness which warrant increased attention, both by the public and by the government. Risk rankings should be only one factor in resource prioritization and regulatory decision making.

9. **Our results are limited by uncertainties in underlying data, none more so than gaps in our ability to confidently attribute cases of foodborne illnesses to specific foods. In order to create the most robust results we could, we conducted a number of sensitivity analyses around incidence estimates, methods of attributing illnesses to foods, and parameters in our monetary and QALY estimates.** Alternative incidence estimates and valuation parameters do not greatly impact rankings because the factors underlying these uncertainties are highly correlated across pathogens. By far, the largest knowledge gap, and the greatest challenge to prioritizing and targeting efforts by both the public and private sectors is what is called "food attribution" data. Improved attribution estimates are needed for all five of the top pathogens, but the needs are most acute with respect to *Salmonella*, *Toxoplasma* and *Campylobacter*. Federal regulatory and research agencies should collaborate to prioritize and fund data collection activities, innovative epidemiologic studies, and research efforts to address these open questions, including efforts to merge or compare information from multiple sources.

Acknowledgements

We have many to thank for their contributions to this project and report. First, we thank the Robert Wood Johnson Foundation for their financial support, without which this report would not have happened, and particularly the tireless enthusiasm of the Foundation's senior program officer Pamela Russo, M.D., M.P.H., and the rest of the Public Health Team. We are also thankful to the Foundation for prior funding support for our risk ranking modeling, and to the USDA National Institute for Food and Agriculture for additional funding.

Second, we must thank the members of our expert advisory panel, who dedicated considerable time to review and provide much-needed comments on our methodology, findings, and report: Douglas Archer, Paul Frenzen, Susan V. Grooters, Craig Hedberg, Lee-Ann Jaykus, Morris Potter, Elaine Scallan, Caroline Smith DeWaal, and Richard Williams. We also thank FDA and FSIS for providing thoughtful feedback, particularly Jeff Farrar, Kara Morgan, Michael Taylor, David Goldman, and Janell Kause.

This report is built upon work done with a number of collaborations that comprise the extended project team; we thank Alan Krupnick, Julie Caswell, Paul Fischbeck, Holly Gaff, Heather Green, David Hartley, Helen Jensen, David Smith, John Lekuton, Michael McWilliams, Diane Sherman, and Jody Tick. For their indispensable help honing our messages, we thank Elizabeth Wenk, Chuck Alexander, Kathy Fackelmann, and others at Burness Communications, as well as Claudia Adrien, Ann Christiano, Joseph Kays, Kathy Momberger and others at the University of Florida. Lastly, we thank the countless other individuals who have provided us with feedback on our risk-ranking efforts in conferences, meetings, and one-on-one conversations over the years.

Chapter 1: Introduction

CHAPTER 1: INTRODUCTION

CDC estimates that one in six Americans get sick each year from food contaminated with bacteria, viruses and parasitic protozoa (Scallan et al. 2011a). While most of these 50 million cases of foodborne illness are mild, they are associated with more than 100,000 hospitalizations and over 3,000 deaths each year. Reducing these numbers has proven to be a challenge because America's food supply is a massive and complex system comprised of hundreds of thousands of firms that provide consumers with hundreds of billions of dollars worth of food each year. Moreover, this system is constantly in flux, due to changing consumption patterns, changing business landscapes, development of new products, and increasingly globalized supply chains.

Federal, state and local government agencies are tasked with overseeing all of these firms , big and small, along the farm to fork continuum – growers, producers, processors, transporters, importers, wholesalers, retailers, restaurants and more. Yet, particularly in today's economic climate, budget resources are limited. Thus, due to these very real and implicit constraints, the FDA and the USDA/FSIS must continually make decisions about how to prioritize efforts and how to allocate their resources to best ensure the safety of America's food.

How the agencies manage their resources has been a focus of a number of studies by the NAS and the GAO (NAS 1998, 2003, 2010; GAO 1992, 2001, 2008, 2011). These reports have described the agencies approaches as overly reactive, rather than proactive, and called for a more science-driven, risk-based approach to food safety. The FSMA, signed into law by President Obama on January 4, 2011, addresses a number of these concerns. It mandates that the FDA take a more risk-based approach to a number of critical food safety activities, such as in the development of new performance standards, produce safety standards, recordkeeping requirements, and foreign supplier verification programs.

While implementation of the FSMA will do many things to improve food safety efforts at FDA and FSIS, it represents only a first step in achieving the long-term vision of a science-driven, risk-based food safety system. Indeed, the most recent NAS report, published in June of 2010, goes significantly further than the FSMA in defining a risk-based approach:

> *In a food safety system, decisions about resource allocation need to be made consistently in order to maximize benefits and reduce risks while also considering costs. Food safety risk managers must consider a wide variety of concerns in their decision making, including the needs and values of diverse stakeholders, the controllability of various risks, the size and vulnerabilities of the populations affected, and economic factors. Although the balancing of diverse risks, benefits and costs is challenging, the lack of a systematic, risk-based approach to facilitate decision making can cause problems ranging from a decrease in public trust to the occurrence of unintended consequences to society, the environment and the marketplace. Moreover, to carry out all its food safety responsibilities and ensure continuity of everyday operations, the FDA needs to have sufficient staff working on food issues to ensure that routine functions continue even when a crisis occurs (p.4).*

The NAS report goes on to define the key analytical attributes of risk-based food safety management:

- "the formulation of a strategic plan that identifies outcomes/goals of the risk-based system,
- broad-based risk ranking to identify the most important risks based exclusively on public health considerations,

- the identification of additional data/information needs upon which prioritization of resources may be based,

- the choice of intervention strategies and allocation of regulatory resources, and

- the evaluation of outcomes. (p.57)."

In short, a risk-based approach to food safety is built upon data, analyses and decision tools that help policy makers: (1) identify the most significant risks from a public health perspective, (2) prioritize opportunities to reduce these risks based upon feasibility, effectiveness and cost of potential interventions, and (3) develop interventions and allocate resources accordingly.

Thus, Step 2 of 6 in the NAS report's recommended components of a risk-based food safety system is for the agency to: "develop or select tools (models, measures or other) for public health risk ranking in consultation with stakeholders; rank risks based on public health outcomes; and report results and solicit feedback (p.82)." With a large and increasing number of foodborne pathogens and a vast array of food products that serve as vehicles for human exposure, one of the key goals of such rankings is therefore to answer the question: which pathogens in which foods cause the greatest burden on public health?

It is this question we hope to answer. This study develops a quantitative and empirical risk ranking approach to compare the relative public health impact of 14 major foodborne pathogens and the food categories with which they are associated. The Foodborne Illness Risk Ranking Model (FIRRM) ranks pathogen-food combinations by estimated public health impact as quantified by five distinct but related measures: the number of illnesses, hospitalizations and deaths, as well as monetary impact based on health valuation, and loss of QALYs, a measure of health-related quality of life.CDC recently published critically valuable new estimates on the burden of illness associated with more than two dozen foodborne pathogens (Scallan et al. 2011a). These new estimates serve as the basis of our analysis, though we expand on their estimates in a number of important ways.

- CDC estimates include only the annual number of illnesses, hospitalizations and deaths associated with each pathogen. They do not account for chronic conditions resulting from foodborne infection – such as kidney failure due to *E. coli* O157:H7 and neuro-muscular syndromes such as paralysis resulting from *Campylobacter* – or serious impacts to developing fetuses – including miscarriage, stillbirth, neonatal death, permanent mental impairment and paralysis – that may result from infection with *Listeria monocytogenes* or *Toxoplasma gondii*. We characterize the major symptoms, severities and likelihoods for both acute and chronic conditions in disease outcome trees that provide a more comprehensive picture. There are a number of chronic sequelae to foodborne illness, such as postinfectious irritable bowel syndrome and reactive arthritis, which we have not estimated.

- In order to compare very different pathogens associated with different symptoms, severities and chronic conditions, we developed two integrated measures of disease burden, which serve as a common metric by which pathogens can be ranked. First, we use the health trees to estimate the impact of these diseases in monetary terms, including the medical costs and productivity losses (lost wages) due to morbidity, as well as less conservative values that incorporate pain, suffering and loss due to premature mortality. Second, we compute QALYs lost due to each pathogen, based on the same health trees. QALYs, as described in Chapter 2, are a tool used in medical decision making to measure the health-related quality of life associated with different health states on a simple scale from 0 (death) to 1 (perfect health). The values between 0 and 1 are derived from large population-based surveys and therefore represent societal views about the pain, suffering, and quality of life associated with all sorts

of health conditions. By computing health impacts both in dollars and QALY loss, we provide two comprehensive, integrated metrics that can be compared across pathogens.

- CDC estimates do not attribute these illnesses to specific types of foods. We draw upon over 10 years of data from foodborne outbreaks, as well as a large, peer-reviewed expert elicitation study we conducted, to assign the relative proportion of each pathogen across more than a dozen food types (e.g. beef, poultry, produce, eggs, dairy products, deli meats, etc.).

- By combining CDC estimates of illness, our health valuation estimates, and these attribution percentages, we estimate the number of annual illnesses, hospitalizations, deaths, dollars and QALY loss associated with more than 150 pathogen-food combinations (e.g. *E. coli* O157:H7 in beef, *Listeria monocytogenes* in deli meats). These pathogen-food combinations can then be ranked, and furthermore, these measures of public health impact can be summed to obtain estimates of public health impact of each food type due to all 14 pathogens combined.

Our hope is that our findings – along with our overall modeling approach – can help inform federal, state and local agencies in their efforts to create a more data-driven, science- and risk-based national food safety system. We fully acknowledge that there are key uncertainties in the data underlying our model, as well as modeling assumptions that others do not agree with. We strive to be transparent, and have included some sensitivity analyses to show the results of alternative assumptions.

Chapter 2 provides a brief overview of the analytical methods and data that serve as a foundation of the model. Chapter 3 provides analytical results, including tables of ranked pathogens, ranked foods and ranked pathogen-food combinations. Chapter 4 provides our findings and recommendations.

Further information about the Foodborne Illness Risk Ranking Model can be found at http://www.thefsrc.org

CHAPTER 2: METHODOLOGY

CHAPTER 2: METHODOLOGY

In a science- and risk-based food safety system, risk managers prioritize food safety hazards and preventive interventions using the best available data on the distribution of risk and how risk can be reduced most effectively and efficiently. As described in the introduction, for foodborne pathogens, this requires an answer to the question: which pathogens in which foods cause the greatest impact on public health?

We developed FIRRM to address this question. FIRRM is a flexible decision tool designed to rank a large number of pathogen-food combinations by multiple measures of public health impact. The model allows users to check the robustness of rankings by permitting them to vary key model assumptions. This feature is designed to facilitate discussion about priorities among users with differing judgments about uncertain model parameters.

Our analysis examines foodborne disease burden from 14 major pathogens attributed to 12 broad food categories – or 168 pathogen food combinations. Disease impacts are measured in direct health impacts (cases, hospitalizations and deaths) as well as two aggregate measures of disease burden, cost of illness (dollars) and QALYs lost.

Although there are a number of complexities in our analysis, our overall analytical approach is relatively straightforward, as shown in Figure 2-1. Each of the following steps are expanded in this chapter:

First, we define the annual number of illnesses due to 14 foodborne pathogens. For the current analysis, we rely upon the most recent estimates by CDC (Scallan et al. 2011a).

Second, we create disease outcome trees that characterize the symptoms, severities and likelihood of major health states, such as hospitalization and death, associated with each of the 14 pathogens. For example, the tree for *Listeria* includes the impacts to developing fetuses, including miscarriage, stillbirth and lifetime mental disabilities. Likewise, the tree for *Campylobacter* includes the fact that some percentage of infections result in neurological sequela in the form of Guillain-Barré Syndrome (GBS).

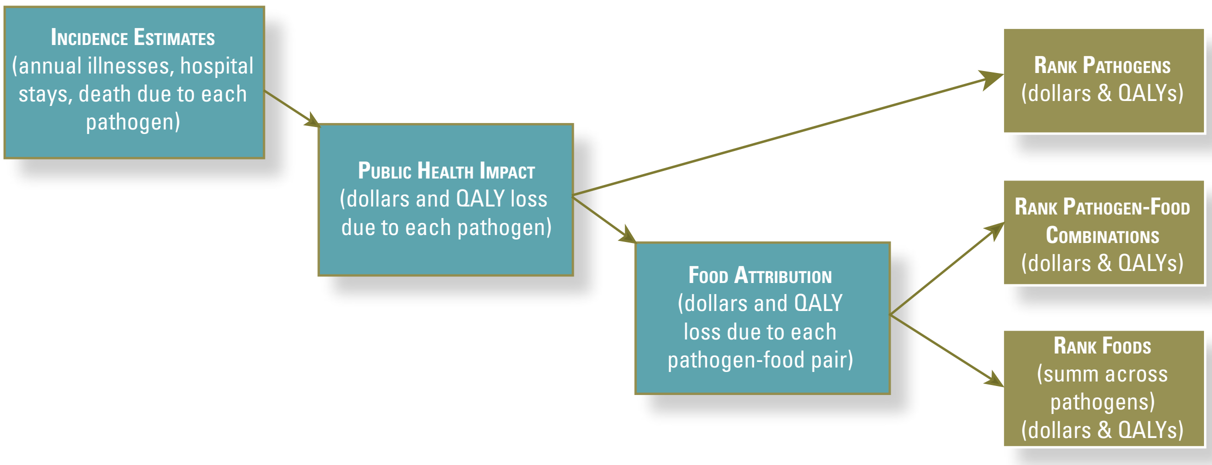
Third, we estimate the "cost of illness" associated with each health state in each tree. For morbidity, we estimate medical costs and productivity losses due to acute infection and chronic sequelae. For premature mortality, we use a value of statistical life (VSL) of $7.9 million. We sum impacts across all branches in each disease outcome tree to obtain costs of illness for each pathogen.

Fourth, we estimate QALY loss associated with each health state in each tree. QALYs are a function of health-related quality of life, measured between 0 (death) and 1 (perfect health), and time. One QALY is equal to one year of perfect health, or two years of 50 percent quality of life. QALY loss is the difference between quality of life with and without an ailment over some period of time. We use the EQ-5D instrument to estimate QALY loss for each health state (Shaw et al. 2005), then sum across the branches of each disease outcome tree to obtain QALY loss for each pathogen.

Fifth, for each pathogen, we estimate the proportion of illnesses due to each of 12 food categories based on an analysis of CDC outbreak data. For each pathogen, we compute the percentage of total outbreaks from 1998-2008 associated with each of the food categories. For four pathogens in which outbreak data are insufficient (*Campylobacter* spp., *Cryptosporidium parvum*, *Toxoplasma gondii* and *Yersinia enterocolitica*), we use the results of a peer-reviewed expert elicitation conducted as part of this study.

Sixth, by applying these food attribution percentages to estimates of dollar and QALY impacts for each pathogen, we compute values for each pathogen-food pair. For each food category, we then sum dollars across all 14 pathogens to estimate the public health impact measured in dollars for each food category. We do the same for QALYs. We also calculate the average of rankings based on QALYs and on dollars to provide another, aggregate perspective on overall disease burden.

Figure 2-1: Steps in Foodborne Illness Risk Ranking



In this chapter, we explain these steps in greater depth.

Estimating Incidence

The first step towards estimating the public health impact of pathogen-food combinations is to determine the overall burden of each relevant pathogen in terms of the number of annual estimated illnesses, hospitalizations and deaths. CDC epidemiologists published groundbreaking estimates of foodborne disease incidence for the United States in 1999 (Mead et al.), and just last year, CDC published revised and updated estimates for 31 pathogens (including sub-types) (Scallan et al. 2011a). These new estimates form the basis of our analysis.

We include 14 foodborne pathogens from Scallan et al. (2011a) in our analysis. These 14 pathogens represent over 95 percent of the annual illnesses and hospitalizations, and almost 98 percent of the deaths CDC attributes to all 31 foodborne pathogens in its study of foodborne disease incidence in the U.S. (Scallan et al. 2011a). They include those pathogens monitored by FoodNet surveillance, plus norovirus, *Toxoplasma gondii* and *Clostridium perfringens*. The FoodNet pathogens are included both because these have been identified as of high priority by CDC and state departments of public health and because FoodNet is the nation's strongest foodborne surveillance program with the best data on incidence of disease. The other three pathogens are included because they rank high in recent CDC incidence estimates.[4] Norovirus is the leading cause of overall cases of foodborne illness and second leading cause of hospitalizations. *Toxoplasma gondii* is the second leading cause of deaths, and *C. perfringens* was estimated to cause the third highest number of cases of illness.

4 Our analysis was originally done based on older CDC estimates of foodborne incidence (Mead et al. 1999), and updated to reflect new CDC estimates published in December (Scallan et al. 2011a). The importance of the three non-FoodNet pathogens was similar in earlier estimates.

Table 2-1: Mean estimates of annual domestic incidence of foodborne disease, sorted by number of illnesses

Pathogen	Illnesses	Rank by illnesses caused	Hospital-izations	Rank by hospital's caused	Deaths	Rank by deaths caused
Norovirus	5,461,731	1	14,663	2	149	4
Salmonella spp.	1,027,561	2	19,336	1	378	1
Clostridium perfringens	965,958	3	438	10	26	8
Campylobacter spp.	845,024	4	8,463	3	76	5
Shigella spp.	131,254	6	1,456	6	10	10
E. coli STEC non-O157	112,752	7	271	12	0	20
Yersinia enterocolitica	97,656	8	533	9	29	7
Toxoplasma gondii	86,686	9	4,428	4	327	2
E. coli O157:H7	63,153	12	2,138	5	20	9
Cryptosporidium spp.	57,616	13	210	14	4	15
Vibrio parahaemolyticus	34,664	14	100	16	4	16
Vibrio spp., other	17,564	16	83	21	8	12
Cyclospora cayetanensis	11,407	21	11	27	0	20
Listeria monocytogenes	1,591	24	1,455	7	255	3
Vibrio vulnificus	96	28	93	18	36	6
Subtotal (14 pathogens)	8,914,713		53,678		1,322	
Total (all 31 pathogens)	**9,388,075**		**55,961**		**1,351**	

Note: Values and rankings represent scoring among the 31 pathogens included in Scallan et al. (2011a). Eleven pathogens are estimated to cause no deaths, all tying for 20th place in number of deaths.

Estimating Public Health Impact

The second step in estimating the public health impact of pathogen-food combinations is to develop integrated measures of disease burden for each relevant pathogen. We estimate the cost of illness associated with each pathogen, as well as the QALY loss.

Integrated measures such as cost of illness and QALY loss allow comparison of the burden of disease across pathogens with very different incidence, symptoms and severities. Summary statistics such as the number of annual illnesses, hospitalizations and deaths each provide narrow and often conflicting pictures of relative disease burden. For example, norovirus causes five times as many illnesses as *Salmonella*, but most of these are mild, while *Salmonella* causes more hospitalizations and more than twice as many deaths per year (Table 2-1). *Listeria* ranks as the 24th pathogen of 31 in terms of illnesses, 3rd in deaths caused and 7th as a cause of hospitalizations.

Even rankings on a single health statistic, like hospitalizations, mask very meaningful differences in the severity and timing of health impacts. For example, hospitalizations with *E. coli* O157:H7 tend to be much more serious than those with norovirus. Perhaps more importantly, these summary measures ignore critically important health consequences of foodborne infection, such as the chronic disease that can follow an acute infection. An *E. coli* O157:H7 infection can result in kidney failure, lifelong dialysis, organ transplants diabetes, neurologic sequel, other long-term complications, and shortened life expectancy. *Campylobacter* infection can cause GBS, a painful neuro-muscular disorder that can result in loss of motor control or even paralysis (Poropatich et al. 2010). *Listeria monocytogenes* and *Toxoplasma gondii* both can result in permanent, lifelong mental and physical disabilities in babies. Simple counts of deaths say nothing about the age of those who die; some pathogens predominately cause mortality in infants or young children, while others primarily result in elderly deaths. Conventional public health statistics do not capture this variation in severity and impact.

Both cost of illness and QALY loss are designed to reflect the varying severity and duration of health outcomes in a common metric that can then be aggregated across health states and pathogens. As such, they are considered "integrated measures of disease burden." QALY loss reflects differences in the age of death. We estimate both cost of illness and QALY loss for several reasons. Each of these metrics has different strengths and limitations and addresses different basic policy questions. In part because of these reasons, support for their use varies by scientific discipline and by agency.

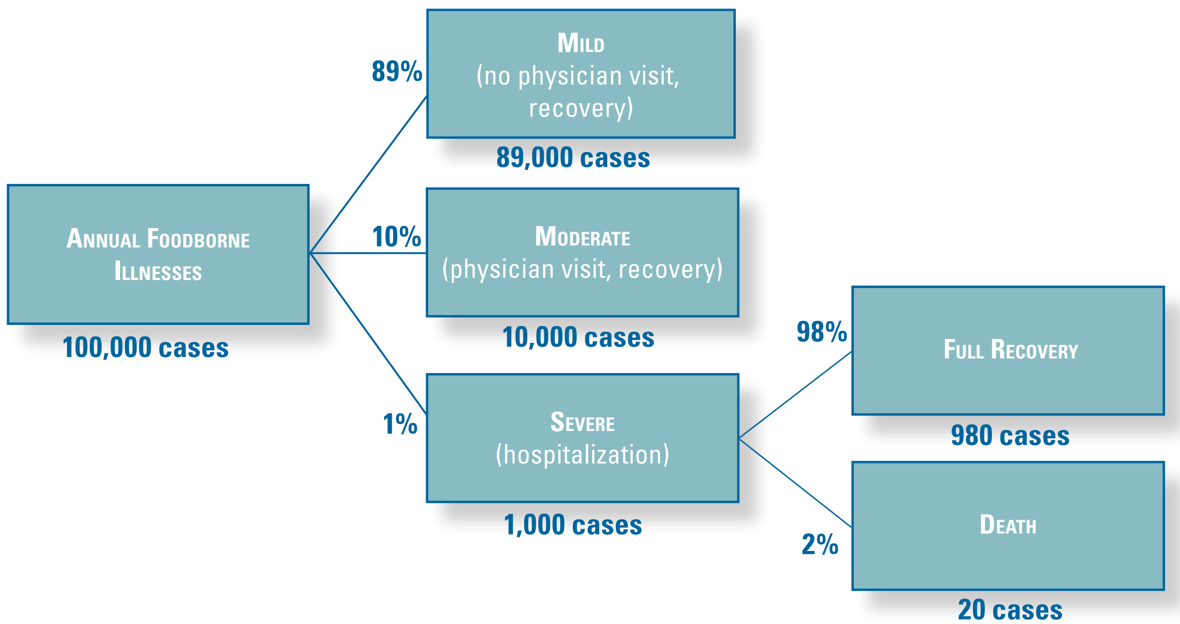
Narrowly defined, cost of illness captures the financial impacts of illness including cost of treatment and lost labor market productivity. We add to this a measure of the value people place on reducing mortality risk, termed a value of statistical life. Health economists view cost of illness as a conservative lower bound on the value of preventing disease, which include avoidance of non-labor market impacts on productivity, avoidance of pain and suffering, concern for others and many other motivations underlying peoples' willingness to pay to prevent disease. Cost of illness is often easier to measure than willingness to pay for disease prevention, and it is often easier for non-economists to understand. Yet as a monetized measure it is directly comparable with costs of preventive actions and with estimates of the benefits of other programs. As a result, cost of illness is one of the methods that have historically been used in public policy analysis. The White House Office of Management and Budget (OMB) requires the use of either cost of illness or estimates of willingness to pay to reduce risk of illness or death in impact analysis for major federal regulatory actions (2003). However, some people, including many health and public health professionals, are uncomfortable with the idea that one can monetize the benefits of health expenditures and thereby compare the value of those actions to other possible actions, like investment in education.

QALYs have nearly the opposite strengths and weaknesses. QALY measures were originally designed for use in a clinical medical setting to help doctors understand the relative effectiveness of alternative courses of treatment. QALY estimates are based on either expert or lay evaluation of the health-related quality of life (measured on a scale from 0 to 1) of experiencing some health condition for an explicit period of time. This impact is measured using one of a variety of scientifically validated, qualitative scales. Use of a non-monetary scale gets around unease about monetizing the benefits of protecting health. Yet QALYs are more abstract than dollars and largely unfamiliar to most people outside of medical and public health professional circles. More importantly, because they are not monetized, QALY estimates can only be used to address the question of cost-effectiveness. They cannot be used to address the question of whether the benefits of a program justify its costs or whether the public return on a particular investment in health is greater than that in something else, for example, transportation infrastructure. As a result, QALYs have not historically been used in public policy analysis. Recently, OMB has permitted their use in regulatory impact analysis, but only as a supplement to monetized measures of regulatory impacts (OMB 2003).

Disease Outcome Trees

The starting point for estimating monetary impacts and QALY loss associated with each pathogen is to identify the outcomes of an illness and characterize their severity and relative frequency. This is presented in a diagram, or disease outcome tree. These trees show the percentage of cases that are mild and require no doctor's care, the percentage that are moderately severe resulting in physician's visits, and the percentage that are severe, resulting in hospitalization. A second branching in the tree shows the percentage of severe cases that subsequently result in death or long-term health conditions (e.g. kidney failure). An example of a disease outcome tree is shown in Figure 2-2.

Figure 2-2: Example Disease Outcome Tree For A Hypothetical Pathogen



We develop empirical disease outcome trees for each pathogen. Where possible, we base our trees on those already developed and peer reviewed. We used trees developed by ERS for *Salmonella*, *E. coli* O157:H7, *Listeria monocytogens* and *Campylobacter* (Buzby and Roberts 1996, Frenzen et al. 1999, Frenzen et al. 2005, ERS 2011). We base our tree for congenital toxoplasmosis on those developed by the researchers at the Dutch National Institute for Public Health and the Environment (RIVM) (Havelaar et al. 2007). For other pathogens, we follow methods used by these and other researchers by basing our trees on available literature, including peer-reviewed journals, published CDC data, Dutch cost of illness estimates and outbreak reports. A bridge is made between these disease outcome trees and QALY estimates by drawing on the clinical medical literature to develop a description of each of the outcomes included in the trees.

An important contribution of our analysis is that long-term disabilities, chronic conditions and latent impacts of acute illness that are not captured by CDC's disease burden estimates are included in our disease outcome trees. We estimate that about 1,900 of the 850,000 annual *Campylobacter* illnesses per year are subsequently hospitalized with GBS, a very serious autoimmune disorder that affects the nervous system and can result in paralysis (Frenzen 2008). GBS is responsible for more than half of the total costs of illness for *Campylobacter*, and more than three quarters of QALY loss. *E. coli* O157:H7 causes hemolytic uremic syndrome (HUS) in a small percentage (0.51 percent) of cases, and an estimated 3.3 percent of these wind up with End-Stage Renal Disease (ESRD), which results in lifetime dialysis, possibly kidney transplants and

a shortened lifespan (Frenzen et al. 2005). Chronic impacts comprise about 25 percent of costs of illness due to *E. coli* O157:H7, and about 15 percent of QALY loss. We estimate that 29 percent of infections with *Cryptosporidium parvum* result in a relapse of mild gastroenteritis (Quiroz et al. 2000). A small percent (0.3 percent) of cases of acute toxoplasmosis result in retinitis and other eye problems, which can cause permanent, largely untreatable blurry vision (Burnett et al. 1998).

Furthermore, both *Toxoplasma gondii* and *Listeria monocytogenes* can cause permanent and devastating damage to developing fetuses, including stillbirths and neonatal death, serious hospitalization during infancy, and permanent, lifelong mental and physical disabilities. We estimate that congenital listeriosis acquired through food results in 61 stillbirths or neonatal deaths per year, as well as in 34 infants born with mild, moderate or severe mental impairment. Congenital listeriosis causes about 15 percent of total costs of illness for *Listeria monocytogenes* and about half of QALY loss. We likewise estimate that congenital toxoplasmosis acquired through food results in 16 stillbirths or neonatal deaths annually, as well as in 216 infants born with mild to serious permanent impairments, ranging from blurry vision, mental impairment and neurological problems such as partial paralysis and abnormal movement. Congenital toxoplasmosis comprises only 5 percent of costs of illness due to *Toxoplasma gondii*, but as discussed in the following section, this is because we lacked sufficient data to estimate chronic medical costs or productivity losses due to chronic physical and mental disabilities for this pathogen. Congenital toxoplasmosis comprises 15 percent of total QALY loss for *Toxoplasma gondii*. These outcomes play an important role in our estimates of both cost of illness and QALY loss.

Cost of Illness Estimates

To estimate the cost of illness associated with a particular pathogen, we first estimate the cost of illness for each health state in the 14 disease outcome trees. Cost of illness includes values for both morbidity and mortality. Our estimation methods for valuing the cost of morbidity were designed to be as consistent as possible with the USDA Economic Research Service (ERS) cost of illness estimates for *Salmonella*, *Campylobacter*, *E. coli* O157:H7 and *Listeria monocytogenes*. These costs include both cost of treatment and lost labor market productivity. For each morbidity health state, we sum the medical costs and productivity loss and multiply the result by the number of annual cases we estimate of that state in the disease outcome tree. For deaths, we replace the ERS annuity method with a standard application of value of statistical life estimates as typically done in federal regulatory impact analysis. This is then multiplied by the number of deaths. We then sum across all of the health states in each tree (morbidity and mortality) to obtain the total public health impact of that pathogen in dollar terms. A brief description of the data and assumptions used to derive these estimates follows.

Medical costs include physician and emergency room visits, hospitalization, outpatient treatment and long-term care for permanent or chronic conditions. For foodborne salmonellosis, *Campylobacter*iosis, illness due to *E. coli* O157:H7 and listeriosis, we use the most recent ERS estimates of these costs updated to 2009 dollars following the ERS choice of price indices. Hospitalization accounts for the largest share of medical costs. For Cryptosporidium, norovirus, *Shigella*, *Toxoplasma gondii* and Yersinia, we base estimates of hospital costs on the Nationwide Inpatient Sample (NIS) for 2001-2003. The remaining five pathogens did not have sufficient coverage in the NIS to allow estimation of hospital costs from that source. For these pathogens we assume that costs of an individual hospitalization are the same as for a proxy pathogen with similar symptoms, severity and duration (though the number of hospitalizations is based on CDC statistics for that pathogen) . Thus, we assume that costs per hospitalization of with Cyclospora are the same as costs per hospitalization with Cryptosporidium. We report species specific incidence, hospitalization and fatality rates drawn from Scallan et al. (2010) for *Vibrio* vulnificus, *Vibrio parahaemolyticus*, and other non-choleric *Vibrio* spp., but costs of individual hospital visits for all three species of *Vibrio* are assumed to mirror per hospitalization costs of similarly severe cases of *Listeria monocytogenes*. Likewise, costs per hospitalization

with *E. coli* non-O157 STECs mirror *E. coli* O157:H7, and costs per hospitalization with C. perfringens mirror norovirus. We base non-hospitalization health care costs on ERS estimates. For each health state in each tree, we assume the number of visits to physicians, emergency rooms and outpatient clinics mirrors that of the most similar health state estimated for foodborne salmonellosis; we then apply ERS costs per visit (which are assumed not to vary by pathogen). The only pathogen for which costs of outpatient prescription and non-prescription medicines are included is *E. coli* O157:H7, for which they account for less than 1 percent of total medical treatment costs estimated by ERS. There is substantial uncertainty about these estimates; they are therefore omitted from estimates for other pathogens as de minimis.

Productivity loss per day of illness is estimated as average daily wage adjusted by a population employment factor reflecting the employment rate of people of the age of those who become ill. As in medical costs, we base our estimates on those of ERS. ERS uses an age weighted hourly wage and takes into account the age distribution of illness. We believe the level of uncertainty in this analysis does not justify this level of precision. To remain roughly comparable to the ERS analysis, we use the mean productivity loss per day for *Salmonella*, averaged across all severities, for all acute illnesses. This is multiplied by the number of work days lost; work days lost is a function of duration, adjusted for severity and a five-day work week. Following ERS assumptions for salmonellosis, mild illnesses not requiring a physician visit result in 0.25 work days lost for each day of symptoms, while the rate for moderate illnesses is 0.33. Productivity losses due to chronic sequelae are estimated somewhat differently. Productivity losses due to chronic impacts resulting from congenital listeriosis are computed as degree of impairment multiplied by average lifetime productivity. For *Campylobacter*-associated GBS, productivity losses are equal to lifetime earnings forgone due to disability for patients who cannot return to work. For congenital toxoplasmosis, we were able to develop disease outcome trees with full descriptions of the associated chronic health states. However, we were unable either to compute the cost of illness for these states or find estimates in the published scientific literature. Thus, our cost of illness estimates for *Toxoplasma gondii* are more conservative, relative to other pathogens, than our QALY estimates.

Federal government analysis of the impacts of major government actions designed to reduce risk of death use a measure of public willingness to pay for these risk reductions as a measure of program benefits. This measure has conventionally been called the “value of a statistical life” (VSL), though EPA is considering changing its name to “value of mortality risk”. Empirical estimates of VSL are based either on observing the amount people spend in their private lives to reduce mortality risk or on surveys of the public. Implicitly, the measure captures all motivations that individuals have for protecting life, including avoiding pain and suffering, dread and other non-financial impacts associated with death. We use a VSL of $7.9 million, in 2009 dollars, to value premature mortality due to acute infection, in adults and children. This value is used by EPA and FDA, and is based on an extensive meta-analysis of available economic studies (Viscusi 1993, EPA 2010). We use this same value for perinatal mortality (including stillbirths), and unlike ERS, we do not adjust for subsequent “replacement” pregnancies.

Estimates of QALY Loss

QALY loss is estimated in much the same way as cost of illness in the sense that we compute it for each state in the disease outcome tree, multiply by the number of cases, and sum to obtain total QALY loss for the pathogen.

QALYs are but one class of a broader group of Health-Adjusted Life Years (HALYs), which also includes Disability Adjusted Life Years (DALYs). All of these measures represent health-related quality of life (HRQL)

as a so-called “preference weight” on a scale of 0 to 1, with 0 for death and 1 for perfect health.[5] Estimates of HALY loss simply multiply this preference weight by the duration of those symptoms (as measured in years), and subtract it from either perfect health or average “baseline” population health without that symptom. NAS recently recommended using QALYs based on the EuroQol 5D (EQ-5D) in federal policy analysis (IOM 2006). The argument made by IOM, and others, is that QALYs should be used in this context because these decisions should be based on the preferences and values of the population in question. For this reason, we adopt its use in this study.

The EQ-5D has five domains – mobility, ability for self-care, performance of usual activities, pain and discomfort, and anxiety and depression. Population-based preference weights for all 243 (3^5) possible domain combinations measured by the EQ-5D are computed by surveying a large, representative sample of the population in question; a statistical model is fit to survey results to estimate preference weights. In this survey, individuals are asked to score their health along these five domains on a three point scale (e.g., 0 being “I am confined to bed” and 1 being “I have no problems in walking about”) (see Box 2-1). Respondents are also asked to score their health on a scale from 0 to 1; this allows a statistical association to be made between their domain scores for their current health condition and their 0-to-1 health score. Based on one such survey, population-based preference weights have been computed by Shaw et al. (2005) and used to develop population-based baseline weights by age and gender (Hanmer et al. 2006).

For our analysis, we develop detailed descriptions of the symptoms and severities of each health state. These were then scored against the five EQ-5D domains (see Box 2-1). These scorings were reviewed by medical clinicians experienced with foodborne disease. Results from Shaw et al. (2005) were then used to convert domain scores for each health outcome to a QALY score (or “preference weight”) from 0 to 1 that is valid for the U.S. population. This is then subtracted from the QALY score for average health in the U.S. population to obtain a QALY loss score for that state. This loss score is then multiplied by the duration of time spent in that state to obtain QALY loss for the health outcome. For example, for mild gastroenteritis, patients were assumed to have no problems walking about, no problems with self-care, no problems performing usual activities, and to have moderate pain or discomfort, but are not anxious or depressed. The resulting domain score (0, 0, 0, 1, 0) was then converted to a QALY score (or “preference weight”) of 0.827. Assuming a duration of three days (3/365 in years) and an average population baseline health of 0.8810, each case of mild gastroenteritis results in 0.0004438 QALYs lost.

5 Increasingly, negative values are included on this scale to accommodate health states that people feel are “worse than death.”

Box 2-1: EQ-5D Domain Questions

Mobility

I have no problems in walking about	❏
I have some problems in walking about	❏
I am confined to bed	❏

Self-Care

I have no problems with self-care	❏
I have some problems washing or dressing myself	❏
I am unable to wash or dress myself	❏

Usual Activities *(e.g. work, study, housework, family or leisure activities)*

I have no problems with performing my usual activities	❏
I have some problems with performing my usual activities	❏
I am unable to perform my usual activities	❏

Pain/Discomfort

I have no pain or discomfort	❏
I have moderate pain or discomfort	❏
I have extreme pain or discomfort	❏

Anxiety/Depression

I am not anxious or depressed	❏
I am moderately anxious or depressed	❏
I am extremely anxious or depressed	❏

Attributing Disease Outcomes to Foods

For each pathogen, we estimate the proportion of foodborne illness caused by that pathogen that is associated with consumption of a particular food. The proportions sum to 100 percent across all foods. These estimates attribute burden of illness to one of 12 broad categories of foods. We use two sources of attribution estimates: percentages derived from analysis of CDC outbreak data and percentages derived from a structured expert elicitation survey designed and administered specifically for our model. These two methods use the same food categorizations and are otherwise designed to provide comparable attribution estimates. As explained below our default is to use outbreak attribution estimates, but where there is strong evidence that these are not representative of food attribution for total foodborne disease incidence, we use attribution estimates from our expert elicitation study.

Food Categorization

The first task in food attribution is to determine how to categorize foods. This task is more complex than it may appear at first. Food categorization schemes are unavoidably purpose specific. For example, food categorizations used to analyze food marketing patterns are likely not useful in analyzing nutrition and those useful in studying nutrition may not be useful in studying food risk. Even in studying food risk, categorizations tend to be purpose driven, for example, poultry could be split by species (chicken vs. turkey), by type of processing (ground vs. intact, raw vs. ready-to-eat deli meat, fresh vs. frozen), by origin (domestic vs. imported), and so forth. FDA, FSIS, and CDC are developing their own categorizations under the auspices of the recently formed Interagency Food Safety Analytics Collaboration (IFSAC) (Morgan 2011). The purpose of our analysis is to provide a global picture of the distribution of risk of foodborne illness in the food supply and to do so in a way that is both intuitively clear to consumers and useful to food safety regulators and managers. As a result, we partition the universe of foods into a relatively small number of basic food categories that can be further partitioned on the basis of type of food, processing or source as needed in managing food safety.

We attribute foodborne illness to foods at the point of consumption. We do this for two reasons. First, because we are trying to attribute disease surveillance data, the closest link between these observed illnesses and food is the point of consumption. This is equivalent to analysis conventionally done in toxicology looking at the association between disease and exposure to chemical toxins rather than to their manufacturing plant. Other categorizations are possible and useful for specific purposes, such as attribution to the source of contamination as a means of focusing specific enforcement actions. Second, because microbial hazards can grow as well as be controlled throughout the production, processing, marketing, preparation and consumption process, it remains fundamentally important to food safety management to understand attribution to food at the end of the farm to fork chain.

Food categorization is also driven by data availability. The most comprehensive primary data source available in the U.S. that can be used for food attribution of foodborne illness is CDC's outbreak surveillance data. Numerous categorization schemes have been used to analyze outbreak data for food attribution patterns, including those developed by the UK Health Protection Agency Centre for Infections (HPA) (Adak et al. 2002), by CDC (Painter et al. 2009), and by the Center for Science in the Public Interest (CSPI) (2009).

Our categorization differs from the commodity-oriented scheme developed by CDC (Painter et al. 2009) and is instead based on the consumer-oriented scheme developed by CSPI. For example, in Painter's scheme, chicken deli meat is categorized as chicken, whereas we categorize it as deli meat. Likewise, we have a baked goods category, whereas Painter would attribute to grains and other ingredients. We also do this because food processing and preparation can create risks that are distinct from those associated with the basic commodity.

For example, *Listeria monocytogenes* is frequently associated with ready-to-eat deli meats but not raw meats, whether the type of meat is chicken, beef, pork or turkey. Our scheme also includes a “complex foods” category to handle outbreaks associated with dishes that are not primarily meat-based, that are comprised of multiple types of ingredients, and in which the specific contaminated ingredient was not identified.

Our two-tier food categorization scheme is presented in Table 2-2. For this analysis we use only the 12 broad food categories. We present food sub-categories to provide a clearer picture of the foods included in each category. We found outbreak data too sparse for meaningful interpretation at the sub-category level.

Table 2-2: Food Categories Used in Risk Ranking Analysis

Food	Food sub-category	Food	Food sub-category
Beef	Ground Beef	Seafood	Finfish
	Other Beef (Intact)		Shellfish
	Beef Dishes		Other Seafood
Deli/Other Meats	Deli Meats		Seafood Dishes
	Other Meats	Produce	Fruits
	Other Meat Dishes		Vegetables
Pork	Ham		Produce Dishes
	Other Pork	Beverages	Juices
	Pork Dishes		Other Beverages
Poultry	Chicken	Baked goods	Breads
	Turkey		Bakery
	Other Poultry		Other baked goods and cereals
	Poultry Dishes	Complex foods (Non-meat multi-ingredient dishes)	Salads
Game	Game		Rice/Beans/Stuffing/ Pasta Dishes
Eggs	Eggs		Sandwiches
	Egg Dishes		Sauces/Dressings/Oils
Dairy Products	Milk		Other dishes
	Cheese		
	Ice Cream		
	Other Dairy Dishes		

Outbreak Attribution

Although reported outbreaks represent a small portion of overall illness, they are useful for attribution purposes because they are comprised of actual illnesses where an explicit linkage is often reported between pathogen and food vehicle (Greig and Ravel 2009). Like outbreak-based attribution efforts by CSPI (2009), CDC (Painter et al. 2009) and public health agencies in the United Kingdom (Adak et al. 2002), our approach involves three steps. First, outbreak data is aggregated over some a defined time period. Second, individual outbreaks are assigned to food categories and sub-categories based on the food vehicle identified in the outbreak investigation. Finally, for each pathogen, outbreaks or outbreak cases that fall into each food category are counted and divided by the total number of cases or outbreaks to obtain proportional attribution to the food category.

We created a database of outbreak line listings from CDC outbreak data from 1998 through 2008, the most recent year available. While we would have preferred to confine analysis to only recent years, there are not

enough outbreaks with complete data to restrict analysis to a shorter time window. The resulting database includes nearly 6,200 outbreaks, representing over 180,000 individual cases of foodborne illness. About half of this data had to be dropped from our analysis because no food vehicle was identified in the outbreak investigation. Another 650 outbreaks (24,000 cases) involved multiple suspected dishes (distinct from single dishes with multiple ingredients); these "multi-source" outbreaks were dropped from the analysis. We were left with over 2,800 foodborne outbreaks (87,000 cases) for which both a pathogen and a food vehicle were identified. Table 2-3 shows the number of foodborne outbreaks associated with each pathogen-food pair, by outbreak data.

For the purpose of food attribution, use of outbreak data has limitations. Outbreaks, by definition, reflect unusual occurrences and/or breakdowns in standard prevention approaches. As such, they may not be representative of "normal" transmission patterns for specific pathogens. The intensity with which an outbreak is investigated may be dependent on its size or the presence of some unusual feature: i.e., an outbreak involving 100 persons, particularly if it involves an unusual vehicle, is more likely to be investigated than one involving three persons in which a "usual " vehicle is suspected. The completeness of investigations is also highly dependent on the interest (and time availability) of local health department investigators and the diagnostic capabilities of the local laboratories.

In using outbreak data to estimate food attribution, it is critical to remember that the purpose is to apply these percentages to overall estimates of illness. The vast majority of foodborne illnesses are independent, sporadic cases unassociated with identified outbreaks. The 180,000 outbreak cases in our outbreak attribution dataset, summed over 11 years, correspond to an estimated incidence of 8.9 million cases of illness (see Table 2-1) for the same pathogens, which suggests there are over 500 foodborne illnesses for every reported outbreak case. The larger an outbreak, the more likely it is to represent a major failure in food safety systems and the more likely it is to have been noticed and fully investigated, and the more likely the vehicle is to be identified. Correspondingly, the less likely such an outbreak is representative of the normal pattern of disease. Smaller outbreaks arguably better represent the majority of foodborne illness, though large outbreaks should be included. Our approach is to treat them as equally important: we compute attributable percentages based on the number of outbreak events, rather than the number of outbreak cases. Doing the latter results in attributable proportions skewed heavily by large and unusual outbreaks. Data tables for outbreak events and case counts are provided in Appendix B. Sensitivity analysis on outbreak attribution assumptions are reported in Chapter 3.

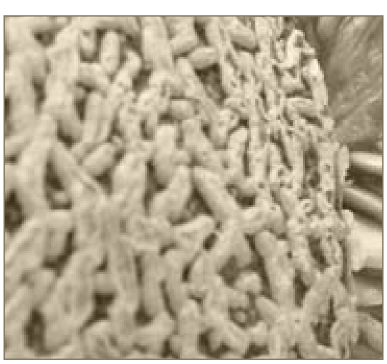


Table 2-3: Percent of outbreaks attributable to food categories 1998-2008

	Campylobacter spp.	*Clostridium perfringens*	*Cryptosporidium parvum*	*Cyclospora cayetanensis*	*E. coli* O157:H7	*E. coli*, non-O157 STEC	*Listeria monocytogenes*	Norovirus	*Salmonella* nontyphoidal	*Shigella* spp.	*Vibrio* spp.	*Yersinia enterocolitica*
Beef	5.4	32.6	0.0	0.0	52.9	40.0	0.0	4.1	6.4	12.2	0.0	0.0
Beverages	0.0	0.0	50.0	0.0	1.9	13.3	0.0	2.1	1.0	0.0	0.0	0.0
Bread and baked goods	0.0	0.0	0.0	0.0	0.6	0.0	0.0	7.8	3.5	0.0	0.0	0.0
Dairy products	48.8	0.5	0.0	0.0	6.5	20.0	28.6	2.2	6.0	2.0	0.0	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	11.2	0.0	0.0	0.0
Game	1.6	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Deli/Other Meats	1.6	2.8	0.0	0.0	3.9	0.0	23.8	1.9	2.8	4.1	0.0	16.7
Complex foods	10.9	24.2	50.0	21.4	14.8	6.7	14.3	45.7	19.0	44.9	0.0	0.0
Pork	2.3	8.7	0.0	0.0	0.0	0.0	4.8	2.9	6.4	0.0	0.0	83.3
Poultry	19.4	26.7	0.0	0.0	0.6	6.7	19.0	8.0	22.1	12.2	1.3	0.0
Produce	6.2	3.3	0.0	78.6	18.1	13.3	4.8	15.5	16.6	16.3	0.0	0.0
Seafood	3.9	1.0	0.0	0.0	0.6	0.0	4.8	9.2	5.1	8.2	98.7	0.0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Number of outbreaks	211	587	17	24	258	39	26	3449	1288	128	79	9
Number of attributable outbreaks	129	393	4	14	155	15	21	1153	688	49	76	6

Notes: Attributable outbreaks exclude "unattributable" and "multi-source" outbreaks. There were zero outbreaks reported due to *Toxoplasma gondii*.

Expert Elicitation

To provide additional information on the representativeness of outbreak attribution by pathogen, and to provide estimates for pathogens for which outbreak data are insufficient, we conducted an expert elicitation of scientists and experts in food safety and public health (Hoffmann et al. 2007, 2008). Past research on expert elicitation approaches suggested that expert judgment would provide a reasonably reliable basis for attribution estimation (Morgan and Henrion 1990, Cooke and Shrader-Frechette 1991).

Expert judgment, collected in a rigorous, structured manner, is increasingly used to fill data gaps in many types of policy models, particularly as the methodologies for capturing uncertainty and validating expertise have matured. Expert elicitation can be used to implicitly or explicitly integrate contradictory or complicated data, and provides a means for providing quantitative values when empirical data are not available. It also

provides an additional means of evaluating uncertainty where data is incomplete. Data collected from our expert elicitation provided additional information on the representativeness of food attribution estimates based on outbreak data. In this report we use expert elicitation estimates to supplement attribution estimates where outbreak data was unavailable or insufficient, namely *Campylobacter* spp., *Toxoplasma gondii*, *Cryptosporidium parvum* and *Yersinia enterocolitica*.

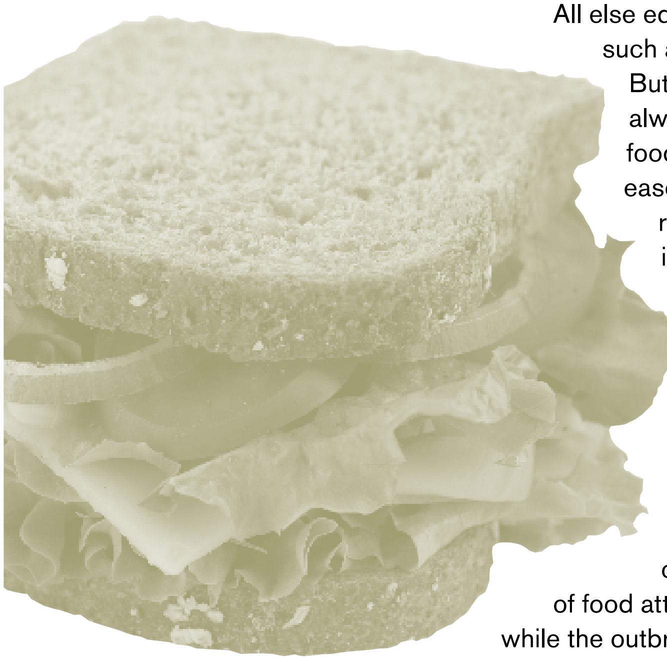
An expert elicitation instrument on food attribution of foodborne illness developed, pretested and administered in 2003 (Hoffmann et al. 2007b). Our expert panel was identified through an iterative process of peer nomination and review among leading food safety scientists, public health officials and policy experts. Sixty two of 89 experts contacted about the study agreed to participate; 45 of these returned completed instruments. Respondents included 24 in federal and state government, 14 from academia, three from industry and three with other professional affiliations. Regression analysis found no systematic association between attribution judgments and professional affiliation, highest degree, discipline of highest degree, years of professional experience or self rating of expertise on individual pathogens or foods. The elicitation protocol included 11 pathogens (*Campylobacter*, *Cryptosporidium*, *Cyclospora*, *E. coli* O157:H7, *Listeria monocytogenes*, norovirus, *Salmonella*, *Shigella*, *Toxoplasma*, *Vibrio* and *Yersinia*) and used the food categorization presented in this report. For each pathogen, participants provided their best estimates of the proportion of foodborne illness caused by that pathogen that was associated with consumption of each food in a typical year. They also gave low and high estimates for their judgments (90 percent credible intervals). In the intervening years, we have published a number of papers on various aspects of the elicitation, including how it relates to analysis of outbreak (Hoffmann et al. 2007a, 2007b, 2008). In this analysis, we use only the average of experts best estimates for attributable fractions, as shown in Table 2-4.

Table 2-4: Percent of illnesses attributable to food categories based on expert judgment, mean of best estimates

	Campylobacter spp.	*Cryptosporidium parvum*	*Cyclospora cayetanensis*	*E. coli* O157:H7	*Listeria monocytogenes*	Norovirus	*Salmonella* nontyphoidal	*Shigella* spp.	*Toxoplasma gondii*	*Vibrio* spp.	*Yersinia enterocolitica*
Beef	4.4	7.4	0.0	67.9	1.6	1.4	10.9	3.1	23.2	0.2	2.2
Beverages	0.0	9.0	1.5	3.2	0.2	4.5	1.7	4.7	0.0	0.8	1.1
Bread & baked goods	0.0	0.3	0.3	0.0	0.2	5.8	0.3	1.9	0.0	0.0	0.0
Dairy products	7.8	5.8	0.4	4.0	23.6	2.9	7.3	3.4	2.4	0.0	12.2
Eggs	2.6	0.3	0.0	0.0	0.3	1.1	21.8	0.9	0.0	0.0	0.1
Game	2.0	5.4	1.3	3.2	0.3	0.6	1.6	0.8	20.4	0.0	2.0
Deli/Other meats	0.9	1.4	0.1	1.8	54.0	9.4	1.9	9.4	1.7	0.2	1.8
Pork	4.4	2.0	0.0	0.6	1.3	1.4	5.7	3.1	41.0	0.2	71.6
Poultry	72.0	1.2	0.0	0.9	2.7	1.5	35.1	4.9	3.7	0.2	1.2
Produce	5.2	59.5	96.1	18.4	8.7	37.3	11.7	60.0	7.0	1.4	3.2
Seafood	0.8	7.7	0.4	0.1	7.2	34.1	2.0	7.8	0.5	97.1	4.7
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Combined Attribution

In this analysis, we rely on both outbreak and expert attribution. Outbreak data is the only comprehensive source of comparable data from which attributable fractions of foodborne illness can be estimated in the U.S. The other published source of comparable attribution estimates that span the food supply in the U.S. is our expert elicitation study. Each source has strengths and weaknesses. They are comparable, but cannot be combined. This is because expert elicitation studies are a type of meta-analysis that explicitly or implicitly take available data and scientific studies, such as outbreak attribution estimates, into account. As a result, to average or otherwise combine outbreak and expert attribution data would be to “double-count” the outbreak estimates.



All else equal, it would be preferable to use primary data, such as the CDC outbreak data, to estimate attribution. But food attribution based on outbreak data may not always be representative of the association between food consumption and foodborne illness for total disease incidence (Batz et al. 2005). Outbreak cases represent a small portion of overall foodborne illnesses and the risk factors in outbreaks may differ from those in sporadic illness. Case-control studies provide additional evidence that for some pathogens outbreak data misrepresents food attribution (Friedman et al. 2004). On the other hand, uncertainty analysis of responses to our expert elicitation indicate that experts believe – based on the scientific literature and professional experience – that for many, but not all, pathogens outbreak data does provide a good representation of food attribution (Hoffmann et al. 2007b). Furthermore, while the outbreak data used in this analysis is from 1998-2008, the expert elicitation was conducted in 2003, and did not include non-O157 STEC or *Clostridium perfringens*.

For this analysis we use a default assumption that outbreak data is representative of food attribution for foodborne illness in the U.S. We then look for evidence to refute this assumption. Our choice of attribution estimate source is made on the totality of this evidence.

Primary data analysis provides some indication of how representative outbreak attribution estimates can be. There are pathogens for which there are simply too few outbreaks with identified vehicles to estimate attribution. From 1998-2008, there were no outbreaks of *Toxoplasma gondii*, only four outbreaks associated with *Cryptosporidium parvum* and seven with *Yersinia enterocolitica* for which the food vehicle was identified (Table 2-3). On the other hand, over this same time period, over 1,500 norovirus outbreaks, over 800 *Salmonella* outbreaks and over 500 *C. perfringens* outbreaks had identified food vehicles. Another indication of the completeness of outbreak data is the ratio of CDC’s estimated annual incidence to the average annual number of outbreak cases in the attribution data, as shown in Table 2-5. This ratio is lowest for *Listeria m.* (44:1), *Cyclospora cayetanensis*. (95:1) and *E. coli* O157:H7 (130:1), and highest for *Yersinia enterocolitica* (12,000:1), *Campylobacter* (1,700:1) and *Cryptosporidium parvum* (1,000:1). By this measure, outbreak data is less representative of overall *Campylobacter*-associated cases than for any other pathogen but *Yersinia*.

Table 2-5: Comparison of Annual Incidence Estimates to Reported Outbreak Cases

	Number of foodborne illnesses (annual)	Total number of reported outbreaks (1998-2008)	Total number of outbreak cases (1998-2008)	Average annual outbreak cases	Ratio of overall illnesses to outbreak cases*
Campylobacter	845,024	211	5,460	496	1,702
C. perfringens	965,958	587	21,446	1,950	495
Cryptosporidium	57,616	17	588	53	1,078
Cyclospora	11,407	24	1,323	120	95
E. coli O157:H7	63,153	258	5,342	486	130
E. coli STEC non-O157	112,752	39	1,554	141	798
Listeria monocytogenes	1,591	26	395	36	44
Norovirus	5,461,731	3,449	101,529	9,230	592
Salmonella	1,027,561	1,288	37,514	3,410	301
Shigella	131,254	128	6,406	582	225
Toxoplasma	86,976	0	0	0	0
Vibrio	52,324	79	1,217	111	473
Yersinia	97,656	9	91	8	11,805

Notes: Annual foodborne illnesses from Scallan et al. (2011a). *Vibrio* includes *V. vulnificus*, *V. parahaemolyticus* and other non-choleric *Vibrio* species. Numbers are rounded.
*Ratio is computed by dividing the first column – the number of annual cases of foodborne illness – by the fourth column – the average annual number of outbreak cases based on 11 years of data. Thus, for *Campylobacter*, 5460/211=496 and 845,024/496=1702 (rounded).

Prior scientific research also provides evidence on the representativeness of outbreak food attribution estimates. Based on four statistical measures of comparison between expert attribution estimates and outbreak attribution estimates for a comparable time period, results from the expert elicitation study strongly indicate that food safety experts do not believe outbreak estimates for *Campylobacter*, *Cryptosporidium*, *Toxoplasma*, and *Yersinia* were representative of food attribution for total disease incidence in a typical year (Hoffmann et al. 2007b). For other pathogens, particularly *Vibrio* spp. and *Cyclospora*, experts strongly agreed that outbreak data was representative. The expert elicitation results also suggest some disagreement with outbreak data for *Salmonella* and *Shigella*. For example, experts were in agreement that poultry played a greater role and eggs a smaller role in causing salmonellosis than indicated by outbreak data. They also saw seafood playing less of a role in foodborne disease caused by *Shigella* than indicated by outbreak estimates.

The design of case control studies permits them to provide very solid empirical evidence on food attribution. Existing studies do not provide comparable data across pathogens and use risk categories that are not amenable to our food categories, but they do provide evidence on the representativeness of outbreak attribution estimates. For example, the FoodNet case-control study on *Campylobacter* found the top three foodborne hazards to be chicken prepared by a restaurant, non-poultry meat prepared by a restaurant, and turkey pre-

pared by a restaurant (Friedman et al. 2004). Nearly 50 percent of *Campylobacter* outbreaks are associated with dairy products, however, followed by poultry (20 percent), complex foods (11 percent) and produce (6 percent). By comparison, experts attribute over 70 percent of *Campylobacter* illnesses to poultry.

Based on the totality of the available evidence, the case against using attribution estimates from outbreak data is strongest for *Toxoplasma gondii*, *Yersinia enterocolitica*, *Cryptosporidium parvum* and *Campylobacter* spp. For these pathogens we use attribution estimates from our 2003 expert elicitation study. For all others, we use attribution estimates based on outbreak data from 1998-2008. Table 2-6 presents the attribution percentages used to compute rankings.

Table 2-6: Percentage of illnesses attributable to food categories, based on expert and outbreak data, as used for risk ranking

	Campylobacter spp.	*Clostridium perfringens*	*Cryptosporidium parvum*	*Cyclospora cayetanensis*	*Escherichia coli* O157:H7	*E. coli* STEC non-O157	*Listeria monocytogenes*	Norwalk-like viruses	*Salmonella* spp.	*Shigella*	*Toxoplasma gondii*	*Vibrio* spp.	*Yersinia enterocolitica*
Data Source*	Exp	Out	Exp	Out	Out	Out	Out	Out	Out	Out	Exp	Out	Exp
Beef	4.4	32.6	7.4	0.0	52.9	40.0	0.0	4.1	6.4	12.2	23.2	0.0	2.2
Beverages	0.0	0.0	9.0	0.0	1.9	13.3	0.0	2.1	1.0	0.0	0.0	0.0	1.1
Bread & baked goods	0.0	0.0	0.3	0.0	0.6	0.0	0.0	7.8	3.5	0.0	0.0	0.0	0.0
Dairy	7.8	0.5	5.8	0.0	6.5	20.0	27.3	2.2	6.0	2.0	2.4	0.0	12.2
Eggs	2.6	0.0	0.3	0.0	0.0	0.0	0.0	0.6	11.2	0.0	0.0	0.0	0.1
Game	2.0	0.3	5.4	0.0	0.0	0.0	0.0	0.1	0.0	0.0	20.4	0.0	2.0
Deli/other meats	0.9	2.8	1.4	0.0	3.9	0.0	40.9	2.3	3.3	4.1	1.7	0.0	1.8
Complex foods	0.0	24.2	0.0	21.4	14.8	6.7	13.6	45.7	19.0	44.9	0.0	0.0	0.0
Pork	4.4	8.7	2.0	0.0	0.0	0.0	4.5	2.9	6.4	0.0	41.0	0.0	71.6
Poultry	72.0	26.7	1.2	0.0	0.6	6.7	4.5	7.7	21.5	12.2	3.7	1.3	1.2
Produce	5.2	3.3	59.5	78.6	18.1	13.3	4.5	15.5	16.6	16.3	7.0	0.0	3.2
Seafood	0.8	1.0	7.7	0.0	0.6	0.0	4.5	9.2	5.1	8.2	0.5	98.7	4.7
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

* Exp = Expert, Out = Outbreak

CHAPTER 3: RESULTS

CHAPTER 3: RESULTS

In this chapter we rank pathogens, pathogen-food combinations and foods based on each of the measures of health burden described in Chapter 2. These rankings reveal new information about the relative burden of foodborne illness in the United States. Some of these results have obvious implications for policymakers, while others point to a need for additional research.

Pathogen Rankings

We estimate that these 14 foodborne pathogens cause $14.1 billion in cost of illness, or over 61,000 QALYs lost per year. Table 3-1 presents the public health impact of all 14 foodborne pathogens, according to five measures of disease burden: annual QALY loss, cost of illness, number of illnesses, hospitalizations and deaths and a combined measure (the average of the QALY and cost of illness rankings).

Table 3-1: Annual Burden of Disease Caused by Fourteen Foodborne Pathogens, Sorted by Share of Overall Public Health Impacts (rank in parentheses)

Pathogen	Combined Rank*	QALY loss	Cost of Illness ($ mil.)	Illnesses	Hospital-izations	Deaths
Salmonella spp.	1	16,782 (1)	3,309 (1)	1,027,561 (2)	19,336 (1)	378 (1)
Toxoplasma gondii	2	10,964 (3)	2,973 (2)	86,686	4,428 (4)	327 (2)
Listeria monocytogenes	3	9,651 (4)	2,655 (3)	1,591	1,455	255 (3)
Campylobacter spp.	3	13,256 (2)	1,747 (5)	845,024 (4)	8,463 (3)	76 (5)
Norovirus	5	5,023 (5)	2,002 (4)	5,461,731 (1)	14,663 (2)	149 (4)
E. coli O157:H7	6	1,565	272	63,153	2,138 (5)	20
Clostridium perfringens	6	875	309	965,958 (3)	438	26
Yersinia enterocolitica	8	1,415	252	97,656	533	29
Vibrio vulnificus	8	557	291	96	93	36
Shigella spp.	10	545	121	131,254 (5)	1,456	10
Vibrio other+	11	149	107	52,228	183	12
Cryptosporidium parvum	12	341	47	57,616	210	4.
E. coli STEC non-O157	13	327	26	112,752	271	0.
Cyclospora cayetanensis	14	10	2	11,407	11	0.
Total		**63,375**	**14,120**	**8,914,713**	**53,678**	**1,322**

* Combined rank is average of QALY loss rank and COI rank.
+ includes *Vibrio parahaemolyticus* and other non-choleric *Vibrio* species

The top five pathogens stand out dramatically, reflecting 90 percent of overall QALY loss and 91 percent of the costs of illness across all 14 pathogens. *Salmonella* ranks first in both QALYs and cost of illness. It is estimated to contribute 27 percent of total QALY loss over all 14 pathogens and 23 percent of the total costs of illness. *Toxoplasma gondii* ranks 2nd overall, contributing 18 percent of total QALY loss and 21 percent of cost of illness. *Listeria monocytogenes* and *Campylobacter* tie for third based on the average of QALY loss and cost

of illness rankings. The difference in the rankings for these pathogens based on QALY and cost of illness illustrates differences in the aspects of disease burden captured by each measure.

Campylobacter accounts for 22 percent of total QALY loss across the 14 pathogens but only 12 percent of total cost of illness. This reflects the fact that mortality dominates the cost of illness measure, and QALY loss is more sensitive to the impacts of GBS. Only 0.23 percent of foodborne *Campylobacter* cases are estimated to be subsequently hospitalized with GBS, but of these 1,900 cases, some result in death and many more result in chronic lifelong conditions such as partial paralysis, continued pain, muscle weakness, sensory abnormalities and fatigue.

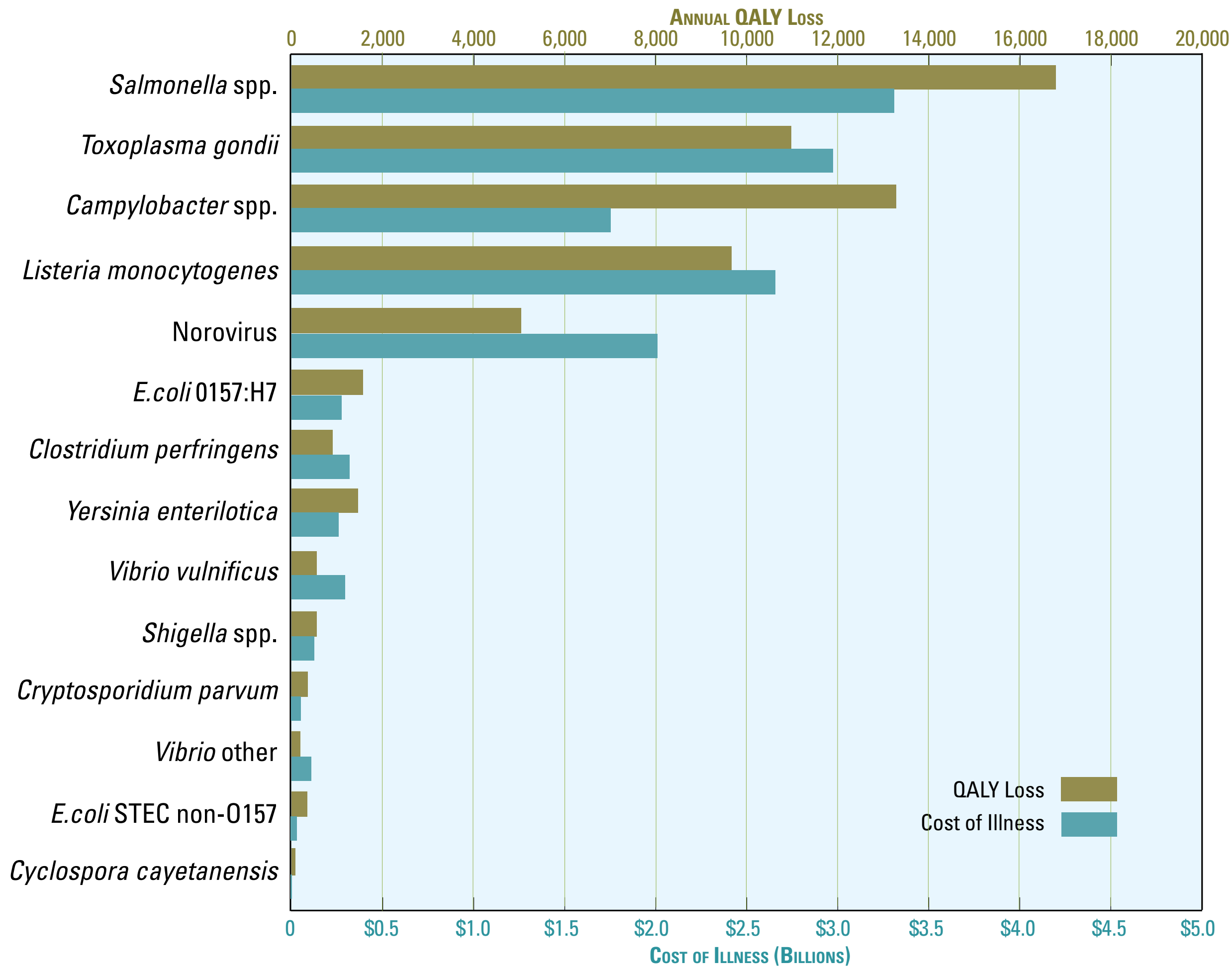
This analysis shows that each of the summary health outcome measures (illnesses, hospitalizations and deaths) and integrated health burden measures (QALY loss and cost of illness) provides somewhat different information on the impact of disease. Looking at the rankings of pathogens across these five measures and the combined ranking measure, some of these measures are highly correlated (Table 3-2). Rankings by cost of illness are very highly correlated to rankings by deaths; rankings by QALY loss have a comparatively higher correlation to hospitalization rankings. Rankings of pathogens by QALY loss and cost of illness are highly correlated.

Table 3-2: Rank Correlation between Ranking of Burden of Disease Caused by Fourteen Foodborne Pathogens, by alternative Public Health Impact Measure

	Combined Rank	Rank by QALY loss	Rank by Cost of Illness	Rank by Illnesses	Rank by Hospitalizations	Rank by Deaths
Combined Rank	1					
QALY loss	.98	1				
Cost of Illness	.98	.95	1			
Illnesses	.41	.48	.36	1		
Hospitalizations	.82	.85	.76	.71	1	
Deaths	.95	.90	.97	.26	.70	1 .

Figure 3-1 illustrates the agreement and differences between estimates of QALY loss and cost of illness across pathogens. As with Table 3-1, it is ordered by the combined QALY/$ rank. It shows that for some pathogens, cost of illness is higher, while for others QALY loss is higher. The biggest disparity is for *Campylobacter*, where QALY loss is very high, but cost of illness isn't. This is driven by impacts due to *Campylobacter*-associated GBS, a very painful and often permanent neurological disorder that results in severely diminished health-related quality of life; cost estimates of chronic GBS states include only medical costs and productivity losses (wages) and essentially ignore pain and suffering. The figure also illustrates the steep drop between the top five pathogens and the remaining nine.

Figure 3-1: Ranked foodborne pathogens, based on estimates of QALY loss and cost of illness



The Top 10 Pathogen-Food Combinations

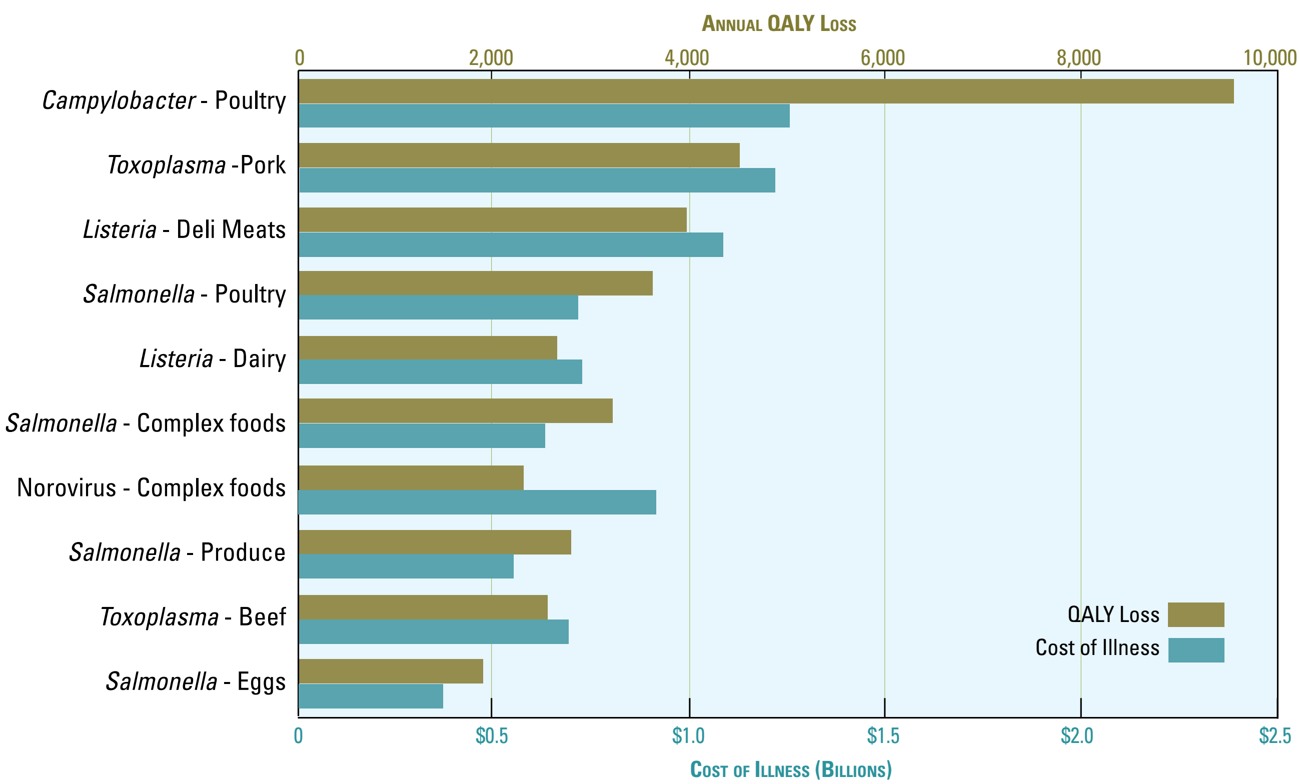
Table 3-3 and Figure 3-2, show the top 10 pathogen-food based on the average of their QALY and cost of illness rankings. The top 50 are shown in Appendix A.

A few key broad findings stand out. First, a relatively small number of pathogen-food combinations account for most of the public health burden from foodborne illness caused by these 14 pathogens. The top 10 pathogen-food combinations are responsible for almost 60 percent of the cost of illness and of the QALY loss associated with these 14 pathogens. The top 50 pathogen-food combinations account for over 90 percent of the impacts due to each of the five measures. Second, only five of the 14 pathogens are found in the top 10 pathogen-food combinations. Third, the set of the top 10 combinations are the same whether ranked by QALY loss or cost of illness, though rankings do differ slightly. Rankings by cost of illness and QALY loss differ from those by summary measures, though rankings by death are most correlated with combined rank.

Table 3-3: The top 10 pathogen-food combinations, ordered by combined rank (rankings by each measure shown in parentheses)

	Pathogen-Food Combinations	QALY loss	Cost of illness ($ mil.)	Illnesses	Hospital-izations	Deaths
1	*Campylobacter* – Poultry	9,541 (1)	1,257 (1)	608,231 (3)	6,091 (2)	55 (9)
2	*Toxoplasma* – Pork	4,495 (2)	1,219 (2)	35,537 (32)	1,815 (8)	134 (1)
3	*Listeria* - Deli Meats	3,948 (3)	1,086 (3)	651 (84)	595 (23)	104 (2)
4	*Salmonella* – Poultry	3,610 (4)	712 (6)	221,045 (11)	4,159 (3)	81 (3)
5	*Listeria* - Dairy products	2,632 (7)	724 (5)	434 (87)	397 (26)	70 (6)
6	*Salmonella* - Complex foods	3,195 (5)	630 (8)	195,655 (12)	3,682 (4)	72 (5)
	Norovirus - Complex foods	2,294 (9)	914 (4)	2,494,222 (1)	6,696 (1)	68 (7)
8	*Salmonella* – Produce	2,781 (6)	548 (9)	170,264 (13)	3,204 (5)	63 (8)
	Toxoplasma – Beef	2,541 (8)	689 (7)	20,086 (43)	1,026 (16)	76 (4)
10	*Salmonella* – Eggs	1,878 (10)	370 (10)	115,003 (17)	2,164 (7)	42 (10)
	Total	**36,915**	**8,151**	**3,861,128**	**29,830**	**765**

Figure 3-2: The top 10 pathogen food-combinations as measured by annual cost of illness and by QALY loss, by combined rank



Campylobacter in poultry is ranked first in both QALYs and dollars, though its dominance in QALY estimates is much larger. This ranking hold despite Campyolobacter ranking only fourth on average rank as a pathogen because *Campylobacter* associated illness is concentrated in poultry. As shown in Table 2-5, experts attribute 72 percent of *Campylobacter* to poultry. FoodNet case-control study results generally support this attribution finding (Friedman et al. 2004).

Toxoplasma gondii is not a "front page" foodborne pathogen, but it is very important from a public health standpoint. CDC estimates that foodborne toxoplasmosis causes 327 deaths annually, second only to *Salmonella* (Scallan et al. 2011a); this high rate of mortality drives its ranking in our cost of illness and QALY rankings. It may be underappreciated as a major foodborne pathogen because it is not associated with outbreaks, and many of its health impacts do not manifest for months or years after infection. Infections tend to manifest themselves clinically in subpopulations with increased susceptibility, including pregnant women and their unborn infants, and persons who are immunocompromised and/or have AIDS. Although conventionally associated with handling of cats and kitty litter, foodborne exposure is now believed to be significant (Dubey 2000; Dubey and Jones 2008; Dubey 2010). CDC estimates 50 percent of toxoplasmosis is acquired through food (Scallan et al. 2011a). The attribution to pork (2nd) and beef (tied for 8th) represents our experts best judgments, but they were elicited in 2003, prior to the 2009 publication of an important FoodNet case-control study that identified eating raw ground beef, eating rare lamb, and eating locally cured, dried, or smoked meats as the most important pathways (Jones et al. 2009).

Listeria monocytogenes in deli meat ranks as the third highest pathogen-food pair in disease burden; this ranking is driven by a large number of outbreaks due to *Listeria monocytogenes* in deli meat prior to 2005. While there have been significant gains over the last decade in reducing contamination rates of pre-sliced, packaged deli meats (USDA 2010), numerous studies have found that retail-sliced deli meats have significantly higher prevalence and levels of *Listeria monocytogenes* (Gombas et al. 2003, Endrikat et al. 2010). FSIS scientists estimate that risks from retail-sliced deli meats are nearly five times higher than prepackaged equivalents, and responsible for 70 percent of the deaths due to the category (Endrikat et al. 2010). *Listeria* in dairy products ranks fifth among pathogen-food combinations. Almost all of this risk is due to soft ripened cheeses, with much of it driven by queso fresco. Queso fresco is a traditional fresh cheese, usually made with unpasteurized milk, common in Mexican cuisine; problems associated with its production, storage, and handling have been found associated both to legitimate, regulated companies as well as by unregistered home producers (MacDonald et al. 2005, Voetsch et al. 2007).

Salmonella ranks first among the pathogens in this study based on either cost of illness or QALY loss, but that burden is distributed across a wide range of food products. *Salmonella* appears four times in the rankings, with the most significant burden of disease associated with poultry (4th). Over 20 percent of the burden is attributed to poultry based on outbreak data, though experts estimate this fraction to be over 35 percent. Salmonellosis due to contaminated produce (tied for 8th) has been recognized by others as a growing concern (DeWaal et al. 2006; Lynch et al. 2009; Maki 2009). In an analysis of foodborne outbreaks from 1998 to 2008, we found that of those due to *Salmonella* in produce, more than half were associated with tomatoes, sprouts or cantaloupes. *Salmonella* in eggs (10th) remains a concern, though risks have significantly declined over the last twenty years (Braden 2006).

Salmonella and norovirus are both highly associated with "complex foods" (tied for 6th), a category created to capture outbreaks associated with non-meat dishes comprised of multiple ingredients, and for which a specific contaminated ingredient could not be identified. The nature of these outbreaks suggests an important role for contamination, cross-contamination, and other mistakes during handling, preparation, and cooking. The role of food workers has long been understood as a critical factor in outbreaks (Greig et al. 2007), and it has been suggested that up to 70% of foodborne illness are acquired outside the home (Chapman et al. 2010). In our analysis of complex food outbreaks between 1998 and 2008, more than 70 percent of those

due to *Salmonella* and 80 percent of those due to norovirus were prepared in professional kitchens. The important role of complex foods to the nation's overall disease burden highlights the importance of food safety efforts at the local and state level, as federal agencies have no direct oversight of most of the places in which food is prepared or sold to consumers.

Food Rankings

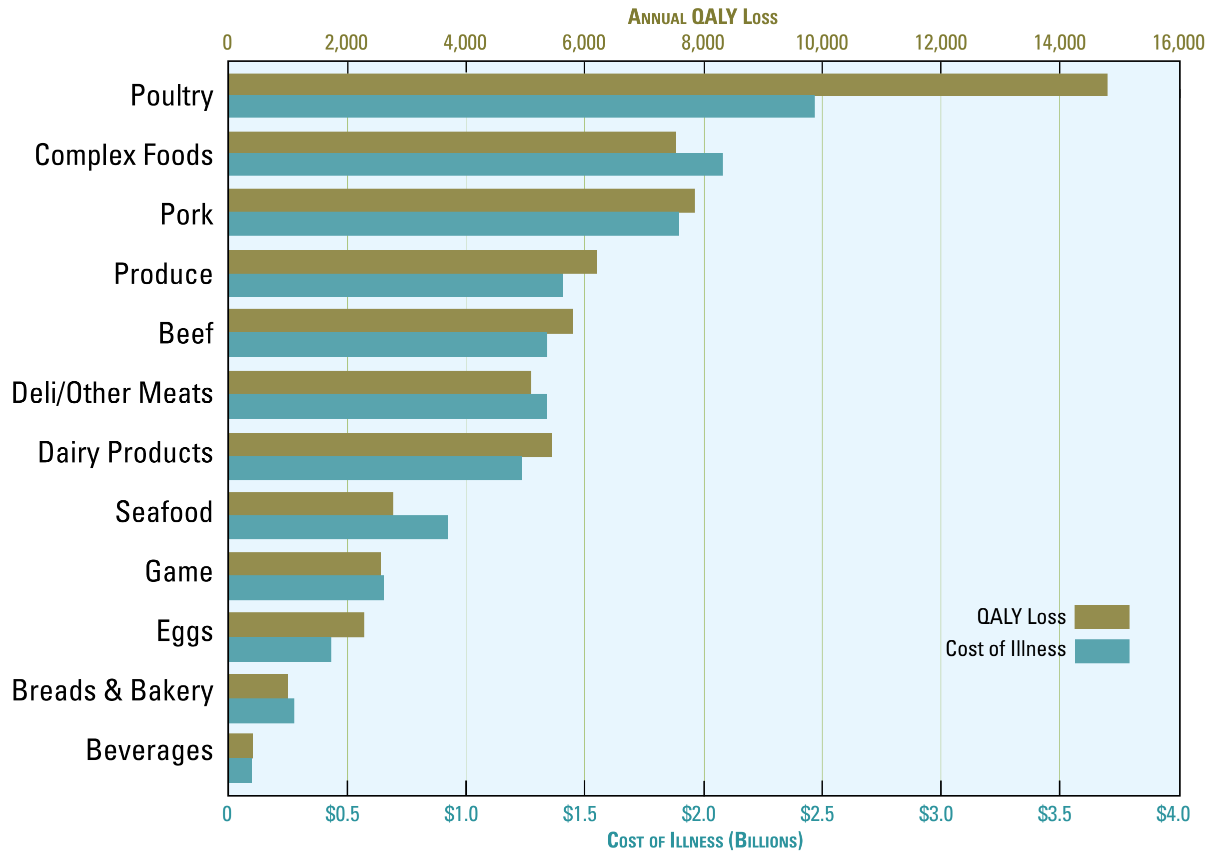
Table 3-4 and Figure 3-3 shows rankings of foods by public health impact. Although poultry causes fewer illnesses than complex foods and fewer deaths than complex foods or pork, it ranks first in both cost of illness and QALY loss. This is because it is the leading cause of hospitalizations and due to considerable burden due to *Campylobacter*-associated GBS. Poultry is followed by complex foods and pork. Pork may be too highly ranked, as these results are due in part to toxoplasmosis attribution by experts that are among the most uncertain in our analysis. One noticeable pattern is that food categories commonly associated with numerous pathogens (poultry, pork, produce) rank much higher than those ordinarily associated with few pathogens (eggs, seafood). Eggs are particularly noteworthy in this respect, for although *Salmonella* in eggs ranks within the top 10 pathogen-food combinations, eggs are one of the lowest ranking food categories overall. This disparity highlights why empirical analysis from multiple perspectives is necessary to understand the complex picture that is arguably oversimplified by such products as top 10 lists.

As noted previously, the role of complex foods in the overall burden of foodborne disease is important from a management perspective. This result highlights the fact that many foodborne illnesses may be caused by mistakes made during handling, storage, and preparation.

Table 3-4: Public Health Impact by Food Category, Summed Across Pathogens, by Combined Rank

	Food Category	QALY Loss	Cost of illness ($ mil.)	Illnesses	Hospitalizations	Deaths
1	Poultry	15,312	2,462	1,538,468	11,952	180
2	Complex foods	8,013	2,079	3,001,858	11,674	189
	Pork	8,017	1,894	449,322	4,334	201
4	Produce	6,204	1,405	1,193,970	7,125	134
5	Beef	6,354	1,338	760,799	4,818	131
6	Deli/Other Meats	5,120	1,341	204,293	1,889	129
7	Dairy products	5,390	1,234	297,410	2,933	114
8	Seafood	2,783	922	642,860	2,937	97
9	Game	2,556	651	46,636	1,106	69
10	Eggs	2,252	428	170,123	2,472	45
11	Baked goods	988	273	462,399	1,833	25
12	Beverages	386	94	146,577	606	8
	TOTAL	**63,375**	**14,120**	**8,914,713**	**53,678**	**1,322**

Figure 3-3: Ranked Food Categories by Aggregate Public Health Impact Due To 14 Foodborne Pathogens



Sensitivity Analyses

We conducted a number of sensitivity analyses to explore the impacts of parameter uncertainties and alternative assumptions.

Incidence uncertainties are driven by underreporting factors (e.g. likelihood that a person with diarrhea visits the physician) that are difficult to measure but which are similar pathogen to pathogen. Thus, while using lower or higher estimates of incidence, drawn from CDC's published confidence intervals (Scallan et al. 2011a), does impact overall estimates of the burden of disease, it does not greatly impact relative rankings of pathogen-food combinations. As shown in Figure 3-4, the set of top 10 pathogen-food combinations remains unchanged under low incidence assumptions, with only minor shifting of ordinal rankings. Under the high incidence scenario, *Listeria* in complex foods moves up from 11th to tie for 10th place with *Salmonella* in eggs.

Likewise, alternate valuation of premature mortality impacts overall estimates of cost of illness more than relative ranking between pathogens. We computed rankings based on two alternative assumptions for the VSL, based on the range published in Viscusi (1993). Assuming a low VSL of $1.4 million, the total costs of illness due to all 14 pathogens drop to $4.4 billion, while assuming a high VSL of $14.2 million results in estimates of cost of illness of $23.2 billion. As shown in Figure 3-5, the low VSL results in only one new pathogen-food pair in the top 10 (norovirus in produce enters the top-10, while *Salmonella* in eggs drops to number 11), while the high VSL does not change the set of top 10 pathogen-food combinations at all.

Figure 3-4: Sensitivity of Pathogen-Food Rankings to Alternative Incidence Assumptions

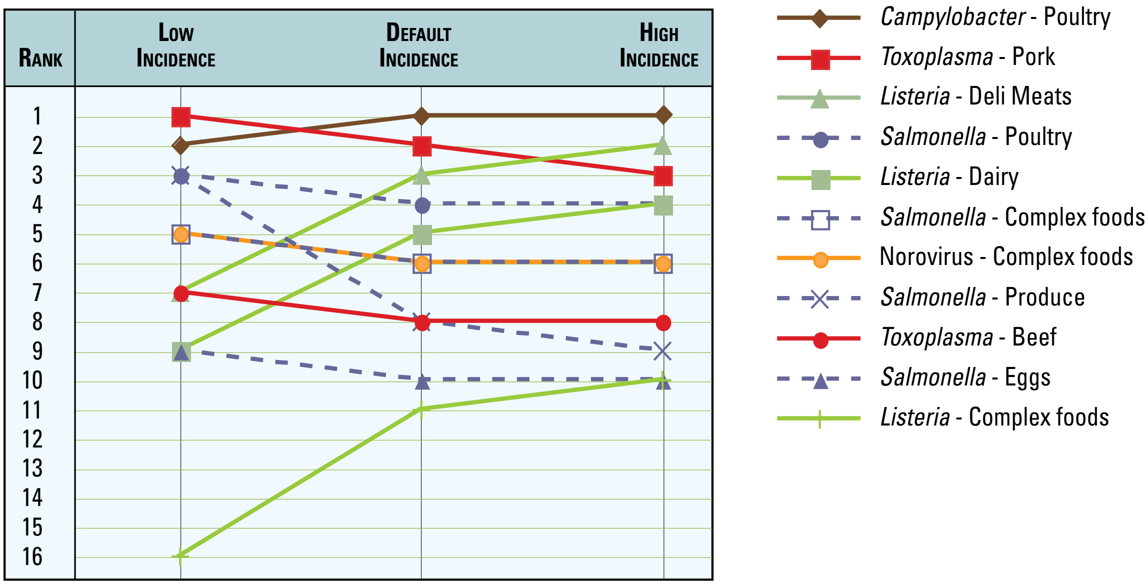
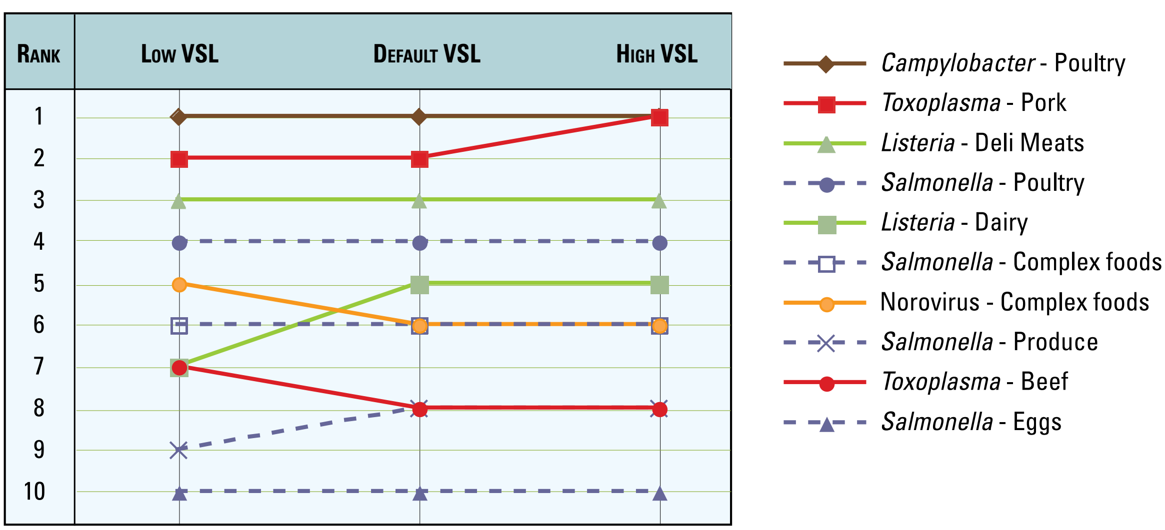
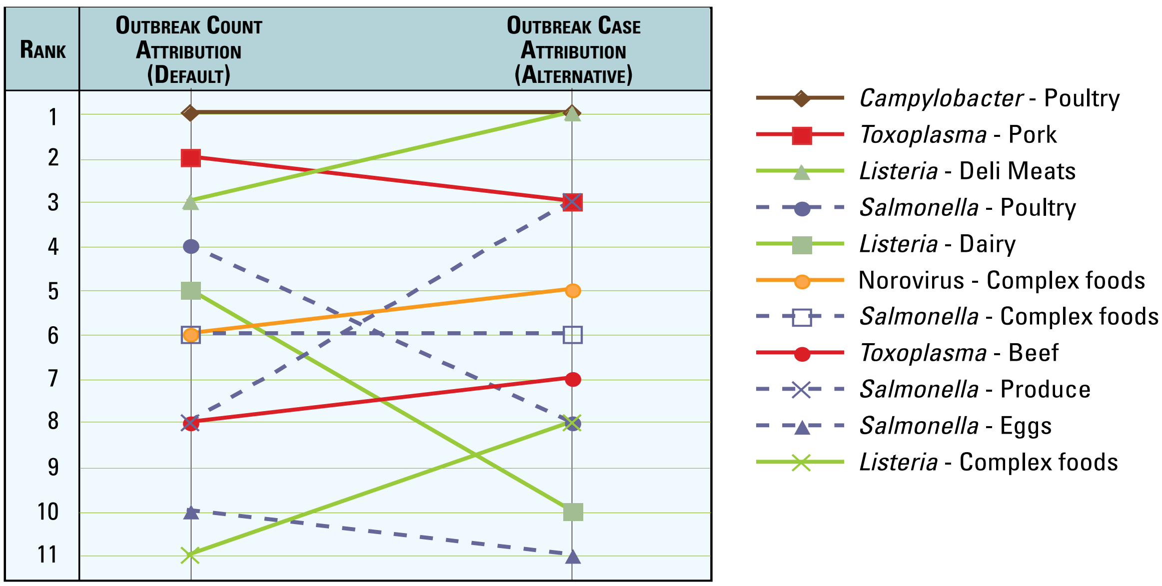


Figure 3-5: Sensitivity of Pathogen-Food Rankings to Mortality Valuation Assumptions



The most significant uncertainties for the purpose of rankings are those surrounding attribution estimates. One of the key assumptions in our outbreak attribution estimates is that we compute attributable fractions based upon the number of outbreaks in each food category (for each pathogen), rather than the number of reported outbreak cases. This was done to avoid bias of very large outbreaks. Assuming outbreak attribution based upon case counts does impact rankings more than alternative incidence or VSL assumptions, as shown in Figure 3-6, though the set of top-10 pathogens remains largely the same (*Listeria* in complex foods enters the top 10 and *Salmonella* in eggs drops out). These shifts are due to the fact that *Listeria* and *Salmonella* attributions are significantly different under case attribution (*Toxoplasma* and *Campylobacter* are based on expert attribution).

Figure 3-6: Sensitivity of Pathogen-Food Rankings to Outbreak Case Attribution



CHAPTER 4: FINDINGS & RECOMMENDATIONS

CHAPTER 4: FINDINGS AND RECOMMENDATIONS

From our analysis and results, we draw the following major findings:

1. **We estimate the public health burden of 14 foodborne pathogens in the United States to be over $14 billion and 60,000 QALYs per year, with 90 percent of these impacts due to only five pathogens: *Salmonella*, Campylobacter, *Listeria*, *Toxoplasma* and norovirus.**

   Across all 14 pathogens in all foods, we find about half of the burden is due to only 10 pathogen-food combinations, a list which includes a variety of commodities including poultry, pork, produce, beef, dairy products and eggs. These 14 pathogens analyzed represent over 95 percent of the annual illnesses and hospitalizations, and almost 98 percent of the deaths, estimated by CDC due to the 31 specific foodborne pathogens estimated by CDC (Scallan et al. 2011a).

2. **Consumption of FDA regulated foods is estimated to cause about half of the overall national burden of foodborne disease.**

   Although attribution data are imperfect, our analysis suggests that poultry, pork and beef cause about $5.7 billion or loss of 30,000 QALYs in disease annually, while produce, dairy products, seafood, breads, beverages and multi-ingredient complex foods (e.g. non-meat dishes served in restaurants, other establishments or homes, as well as processed foods such as peanut butter) cause about $6 billion or loss of 24,000 QALYs in disease burden. Deli meats and eggs cause an additional $1.8 billion and 7,000 QALYs. This can be viewed as a shared USDA/FDA responsibility. Although FSIS regulates deli meat manufacture and processing, FDA has federal responsibility for developing model statutes for food handling in food service and retail food establishment where contamination also occurs. It's important to note that our estimates take current control efforts in the private and public sectors as given. These estimates do not measure of the efficacy of either FSIS or FDA activities.

   The top 10 pathogen-food combinations list flattens a very complicated food system into a simplified picture of pathogens in very broad food categories. Our food categories reflect "foods as consumed," rather than traditional agricultural commodity categories, because of the important role in food handling and preparation as important risk factors. The focus on "foods as consumed" also provides the most direct link to data used to estimate disease incidence. But the ability to prevent, or create, foodborne illness risks occurs throughout the food production, processing, marketing and preparation chain. When considering interventions, the full farm to fork spectrum should be taken into account.

3. **Four of the top 10 pathogen-food combinations represent significant risks to pregnant women and developing fetuses.**

   Listeriosis and toxoplasmosis can both lead to miscarriage, stillbirth and neonatal death, as well as lifelong complications ranging from mild learning disabilities to severe mental disabilities, permanently blurry vision, neurological disorders and paralysis. Our analysis suggests recent past efforts at reducing these risks are insufficient, as four of the top 10 pathogen-food combinations are *Listeria monocytogenes* in deli meats and soft ripened cheese (such as queso fresco made and consumed in Latino communities from raw milk), and *Toxoplasma gondii* in raw or undercooked pork and beef.

Greater efforts to further reduce these risks may be warranted. Possible actions include:

- The content and efficacy of educational outreach materials could be improved. For example, pregnant women are often told about risks of toxoplasmosis due to cats and kitty litter, but are less often counseled about the risks from foodborne toxoplasmosis (Jones et al. 2010). Research and epidemiological data over the past 10 years suggests foodborne toxoplasmosis, due to the handling and consumption of raw or undercooked meat, may be a major pathway for exposure.

- Greater effort could be made to ensure that pregnant women are receiving these messages and understanding and avoiding risks. In a recent national study, fewer than 20% of participating pregnant women were aware of *Listeria* as a risk; of these, less than a third of these understood which foods to avoid, and even fewer actually avoid these foods (Ogunmodede et al. 2005). Likewise, while health care providers are effective and trusted sources of information to pregnant women (Cates et al. 2004, Delgado 2008), too few educate their patients about listeriosis and many are unaware themselves of which foods their patients should avoid (Wong et al. 2004, Bondarianzadeh et al. 2007, Leddy et al. 2010).

- Rates of listeriosis are higher among Hispanic women, with consumption of Mexican-style cheeses a pronounced risk factor (Voetsch et al. 2007, Jackson et al. 2010). Given the outsized risks associated with queso fresco, targeted efforts directed towards this specific commodity and community seem warranted. Spanish-language efforts for pregnant Latinas should be a focus.

- Lack of scientific understanding of how *Toxoplasma* enters the food supply hampers control efforts and makes effective risk communication to consumers difficult. FDA and FSIS, along with CDC, should increase efforts to characterize toxoplasmosis risks. Such efforts include but are not limited to increasing testing of meats and epidemiological studies to further target risky products, behaviors and sensitive subpopulations.

- Both FDA and FSIS should assess whether the risks to this sensitive subpopulation (and other sensitive subpopulations, such as those with AIDS) are sufficient to warrant additional oversight, such as labeling of deli meats or *Toxoplasma* control programs in lamb, mutton, pork, beef or other meats.

4. ***Salmonella* causes more disease than any other foodborne pathogen and according to FoodNet surveillance data. It is one of the few foodborne pathogens that has not significantly declined over the past 10 years.**

According to CDC estimates, it is the leading pathogen in terms of annual deaths and hospitalizations, while our analysis, built on ERS studies, suggests it is the leading pathogen when valued in dollars ($3.3 billion) or in impacts to health-related quality of life (loss of 17,000 QALYs). Our analysis also shows that salmonellosis disease burden is associated with a wide variety of foods regulated by both FSIS and FDA, including significant burdens associated with poultry, produce and eggs. This suggests that reduction of the national burden of salmonellosis will require a coordinated effort by both agencies addressing a broad array of foods.

We recommend the agencies convene a national cross-agency initiative in collaboration with CDC that looks across the entire food system to target opportunities for risk reduction. Such an effort, building on some of the successes of the President's Food Safety Working Group, could include work to create joint prioritizations built on shared data, collaborative research and joint assessments of risks and potential intervention points along the farm to fork spectrum in a variety of key commodities. This work could move forward under the auspices of the Interagency Food Safety Analytics Collaboration (IFSAC),

recently formed by CDC, FDA and FSIS to explore cross-cutting issues such as this. While our analysis did not include further subdivision of the species by serotype or other subtyping methods, there are data suggesting that different serotypes differ in virulence; any comprehensive *Salmonella* control program should incorporate a more careful analysis of comparative risk based on serotype or other subtyping approaches.

Private sector involvement that includes firms of a variety of scales could assist in finding ways in which private sector initiatives or joint public/private partnerships could be used to reduce *Salmonella* risks. With increasing concern about the effectiveness of government actions, any initiative should define food-specific targets for *Salmonella* and collect requisite data prior to and following any interventions to evaluate how well they are functioning and to reassess if further action is needed.

5. **Contaminated poultry has the greatest public health impact among foods. It is responsible for an estimated $2.4 billion or loss of 15,000 QALYs in annual disease burden.**

Poultry is the only single food commodity (e.g. other than complex dishes) that appears twice in our top 10. Its most significant disease burden is caused by contamination with *Campylobacter* and *Salmonella*. This analysis supports FSIS's recent increase in the stringency of *Salmonella* performance standards in broiler chickens for the first time in 15 years and its promulgation of performance standards for *Campylobacter* for the first time in the agency's history (USDA 2009, 2011).[6]

Continued pursuit of improvement in this area is needed, however. FSIS estimates that these new standards will result in 20,000 fewer *Salmonella* cases and 5,000 fewer *Campylobacter* cases each year, but these reductions reflect only a 2 percent and less than 1 percent reduction in foodborne salmonellosis and campylobacteriosis respectively (Scallan et al. 2011a). The NAS and other leading science policy bodies have recommended that monitoring, evaluation, and revision be a critical component of the kinds of innovations FSIS has undertaken.

6. **Considerable burden of disease is caused by food handling and preparation problems in food service and retail settings.**

The role of food workers in the handling and preparation of foods has long been understood as an important factor in foodborne disease. It has been suggested that up to 70% of foodborne illness are acquired outside the home (Chapman et al. 2010), though the portion of foodborne illness caused by failures of food workers is ultimately unknown (Jones and Angulo 2006, Jacob and Powell 2009). *Listeria monocytogenes* in deli meats ranks as the pathogen-food pair with the third highest disease burden in our rankings, and recent studies suggest that the majority of these illnesses are due to retail-sliced deli meats rather than those that are prepackaged (Endrikat et al. 2010). Likewise, FoodNet case-control studies for *Campylobacter*, *E. coli* O157:H7, *Salmonella*, *Listeria* and other pathogens consistently show higher risks for foods prepared outside the home (e.g. Friedman et al. 2004, Kassenborg et al. 2004, Hennessy et al. 2004, Kimura et al. 2004, Varma et al. 2007, Voetsch et al. 2009). In our analysis, complex multi-ingredient dishes, often associated with mistakes in preparation during food preparation and handling, are the 3rd leading food group in terms of associated burden of disease. Depending on the pathogen, 70-80 percent of outbreaks in our dataset due to complex foods were associated with food prepared in restaurants, cafeterias, deli counters, and other professional kitchens.

6 FSIS announced new performance standards in May, 2010, which are set to go into effect in July, 2011 (USDA 2009). These standards specify the maximum number of positive samples for *Salmonella* and *Campylobacter* in sets taken on young chickens and turkey for establishments to remain in compliance. The performance standard for *Salmonella* is being set at 5 samples out of 51 for chickens (9.8%) and 4 of 56 (7.1%) for turkeys. For *Campylobacter*, the maximum number of positive samples is 8 of 51 (15.7%) for chickens and 3 of 56 for turkeys (5.36%). These rates were set based on baseline studies of the entire industry.

This suggests that there is still room for significant improvement in this area and it highlights the importance of food safety efforts at the local and state level, as federal agencies have no direct oversight of most of the places in which food is prepared or sold to consumers. Federal agencies nonetheless have a leadership role in strengthening state and local efforts as part of the national food safety system. Government actions that could improve retail and food service food safety include fully funding state and local inspection activities, increasing adoption of the most recent food code, improving education and training of food workers and government inspectors, and creating incentives to foster improved food safety in the private sector. A number of these actions have been identified by FDA as goals of its Retail Food Safety Initiative, which followed a 10 year study of retail risk factors (FDA 2011a, 2011b). Ultimately, however, food safety responsibilities lie with those producing and preparing the food itself; the private sector must do more to facilitate a culture of food safety that results in measurable improvements to food safety behaviors (Powell et al. 2010).

7. ***Toxoplasma gondii* causes nearly $3 billion or loss of 11,000 QALYs in disease burden annually, making it one of the most burdensome foodborne pathogens, yet our understanding of the pathways for human infection is limited.**

Our data highlight the relative public health impact of *Toxoplasma* infections. CDC estimates 87,000 cases of foodborne toxoplasmosis annually, resulting in over 300 deaths, surpassed only by foodborne *Salmonella* (Scallan et al. 2011a). These infections tend to manifest themselves clinically in subpopulations with increased susceptibility, including pregnant women and their unborn infants, and persons who are immunocompromised and/or have AIDS. Most people show minimal or no symptoms during acute infection, but maintain latent cysts in brain, heart, and skeletal muscle tissue that may reactivate when the immune system is compromised. Estimating the annual incidence of adult toxoplasmosis is difficult because of this latency and lack of acute symptoms, so it is estimated based on population-based, cross-sectional serologic surveys (Scallan et al. 2011a). The government should consider steps to improve surveillance of both adult and congenital toxoplasmosis, such as making acute toxoplasmosis and/or congenital toxoplasmosis nationally notifiable diseases to ensure they are reported (Bénard et al. 2008). Longitudinal or targeted cross-sectional studies may help to better quantify incidence of toxoplasmosis and chronic sequelae, as might advanced mathematical modeling (Berrébi et al. 2010, Walker et al. 1992, Welton and Ades 2005).

Our understanding of the pathways for human infection from *Toxoplasma* is limited and affects our ability to manage risk of foodborne toxoplasmosis. *Toxoplasma* is most commonly associated with cats, and while cats are the definitive host, CDC estimates that 50 percent of infections are foodborne (Dubey 2000, Scallan et al. 2011a). Before strategies can be developed for reducing foodborne toxoplasmosis risks, a better understanding is needed of how much *Toxoplasma* risk is attributable to different foods.

Historically, foodborne toxoplasmosis has been associated with pork. But tests on pork show a major decline over the last fifteen years, while the number of other foodborne vectors associated with *Toxoplasma* has increased (Dubey 2000, Dubey and Jones 2008, Dubey 2010). A recent case-control study by CDC found the leading foodborne risks to be eating raw ground beef, rare lamb or locally produced cured, dried or smoked meat (Jones et al. 2009). Handling raw meat, drinking unpasteurized goat's milk and consuming raw shellfish were also identified as risks as were consumption or handling of wild game. The risks associated with backyard production of produce and animals (particularly chickens) need to be better understood; this may be an emerging risk factor, as *Toxoplasma* contamination rates for both have been shown to be higher when produced around domestic cats. The relative importance of these food, water and non-food pathways is very poorly understood, which poses major challenges for regulatory agencies to target interventions.

This lack of knowledge combined with the remarkably high health burden associated with foodborne toxoplasmosis clearly points to the need for significantly more effort in understanding and characterizing the sources of these illnesses. Significant increases in data collection, epidemiologic studies and scientific research are needed. This effort needs to involve both regulatory and research agencies in the federal government as well as researchers in universities and the private sector.

8. ***E. coli* O157:H7 and non-O157 STECs cause about $300 million or loss of 2,000 QALYs in disease burden annually.**

Although the overall burden of disease is not as high as the top five pathogens, individual cases of disease are devastating both physically and financially, and often occur in small children, a sensitive subpopulation that warrants particular protection.

According to FoodNet data, the rate of infection in 2009 is 60 percent of the rate in 1996-1998 (CDC 2010). Moreover, due to greater recognition of the disease, faster diagnostics, and more timely institution of appropriate therapies, far fewer patients die today than a decade ago (Gould et al. 2009, Collins and Green 2010). CDC's most recent estimate of the mortality rate (Scallan et al. 2011a) is a dramatic 40 percent of the rate estimated ten years ago (Mead et al. 1999).[7] At the same time, studies have shown non-O157 STECs to be increasing, and surveillance systems for these strains may be insufficient (Hughes et al. 2006, Osterholm 2011).

Chronic sequelae resulting from HUS are a significant contributor to the disease burden , but estimates of QALY loss and cost of illness are heavily driven by the number of deaths due to acute illness. CDC estimates that STECs cause 20 deaths annually, compared to 380, 330, and 250 due to *Salmonella*, *Toxoplasma gondii* and *Listeria monocytogenes*, respectively. Our estimates of chronic impacts are conservative. They do not estimate the impacts of other serious postinfectious conditions, such as diabetes, hypertension, cardiovascular disease, or irritable bowel disease (Suri et al. 2009, Clark et al. 2010, Pennington 2010). Even if they were included, however, these impacts would not likely change the top rankings.

Our findings do not suggest that STECs are unimportant or that special attention to *E. coli* O157:H7 is unwarranted. Rather, the lesson should be that both the public and government decision makers have been less aware of other pathogens, such as *Toxoplasma*, that are causing significant disease burden and which therefore deserve greater attention than they are currently receiving.

This finding also highlights the fact that all rankings are inherently limited by the metrics used. The metrics used in our rankings, as well as the rankings implied by epidemiological data such as the CDC incidence data, focus on average population risk. Other risk characteristics may be of great importance to the public and to government decision makers. For example, for some decisions risk per serving may be more informative than total or average public health burden. The great attention given to both *E. coli* O157:H7 and non-O157 STECs stems in part from the fact that many of the victims of foodborne illness associated with them have been young children. Just because a pathogen-food pair does not rank in a top 10 list does not mean it is unimportant. Distributional concerns, such as the impact on vulnerable populations, may be important policy considerations, but are reflected in our results in only a limited way through the structure of the QALY metrics. These limitations are reasons why we recommend that risk rankings and other analyses like ours should be used as one factor in prioritization and regulatory decision making.

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7 Had the mortality rate stayed the same as reported in 1999, our estimates of the costs of illness would have doubled to $530 million. This assumes 53 estimated annual deaths instead of 20, with requisite decreases in the number of cases in other severity categories. Even under this assumption, *E.coli* O157:H7 in beef would have ranked 12th or 13th among pathogen-food combinations on the basis of cost of illness.

9. **Our results highlight the limitations data quality places on the ability to make risk-informed food safety policy decisions. We find the limitations in the ability to confidently attribute cases of foodborne illnesses to specific foods poses the greatest challenge.**

To test the robustness of our results, we have conducted a number of sensitivity analyses around incidence estimates, methods of attributing illnesses to foods and parameters in our cost of illness estimates. As discussed in Chapter 3, uncertainty in food attribution impacts rankings of pathogen-food combinations more than alternate assumptions in incidence estimates or cost of illness estimates. This is because uncertainties in incidence and cost of illness are highly correlated across pathogens.

The degree of uncertainty about attribution varies by pathogen, but as has been stated previously, better information on food attribution is needed for most of the major pathogens (Batz et al. 2005, Pires et al. 2009, NAS 2010). As previously mentioned, there is very little empirical data to support *Toxoplasma gondii* attribution estimates. Unlike the majority of foodborne pathogens, *Toxoplasma gondii* is a parasite, rather than a bacteria or a virus, and many of its impacts are latent. Adequate parasitological capacity may not exist in the agencies at this time to increase attention on *Toxoplasma* and may be contributing to the relative lack of attention it has received. For different reasons, there is significant uncertainty about *Salmonella* and *Campylobacter*. These pathogens are so pervasive that more accurate attribution is key to identifying interventions. Numerous approaches, including the use of serotyping, PulseNet, and microbial subtyping methods, should be pursued. Likewise, because norovirus is highly contagious, the key role of person-to-person transmission makes attribution difficult.

This finding supports the coordinated effort federal regulatory and research agencies are undertaking (the aforementioned IFSAC) to share data and collaborate on developing better attribution methods and estimates. The expert elicitation study conducted as part of this research effort provides insights into the role that methodology can play in addressing scientific uncertainty about attribution estimates (Hoffmann et al. 2007b).

The long-term impacts of foodborne pathogens are increasingly understood as a significant component of their burden of disease (e.g. Lindsay 1997; Ternhag et al. 2008; Gradel et al. 2009). Our analysis shows that chronic conditions and latent impacts to developing fetuses are important components of the costs of illness and impacts to health-related quality of life. Three of the top five pathogens and five of the top 10 pathogen-food combinations are associated with significant health impacts beyond those due to acute infection. Our efforts to estimate the impacts of additional chronic sequelae, such as reactive arthritis and irritable bowel syndrome, were stymied by the lack of solid, empirical data on the rates of chronic sequelae, their defined association with specific infectious agents, and the quantitative likelihoods of major symptoms, severities, durations and outcomes, and the economic costs of these impacts. Increased surveillance and research on the long-term impacts of foodborne disease is critical to fully assess the public health impacts of these risks.

References

REFERENCES

Adak GK., Long SM. and O'Brien SJ. 2002. Trends in indigenous foodborne disease and deaths, England and Wales: 1992 to 2000. *Gut* 51, 832- 841.

Batz MB, Doyle MP, Morris G Jr, Painter J, Singh R, Tauxe RV, Taylor MR, Lo Fo Wong DM; Food Attribution Working Group. 2005. Attributing illness to food. *Emerg Infect Dis* 11:993–999.

Behravesh CB, Mody RK, Jungk J, Gaul L, Redd JT, et al. 2011. 2008 Outbreak of Salmonella Saintpaul infections associated with raw produce. *N Engl J Med Mar* 10;364:918-927.

Bénard A, Petersen E, Salamon R, Chêne G, Gilbert R, Salmi LR, for the European Toxo Prevention Study Group (EUROTOXO). 2008. Survey of European programmes for the epidemiological surveillance of congenital toxoplasmosis. *Euro Surveill* 13(15):pii=18834. *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=18834*

Berrébi A, Assouline C, Bessières MH, Lathière M, Cassaing S, Minville V, Ayoubi JM. 2010. Long-term outcome of children with congenital toxoplasmosis. *Am J Obstet Gynecol* Dec;203(6):552.e1-6.

Bondarianzadeh, D., Yeatman, H. and Condon-Paoloni, D. 2007. *Listeria* education in pregnancy: lost opportunity for health professionals. *Australian and New Zealand Journal of Public Health* 31: 468–474. doi: 10.1111/j.1753-6405.2007.00120.x

Braden CR. 2006. *Salmonella enterica* serotype Enteritidis and eggs: A national epidemic in the United States. *Clin Infect Dis* 43(4): 512-517 doi:10.1086/505973

Burnett AJ, Shortt SG, Isaac-Renton J, King A, Werker D, Bowie WR. 1998. Multiple cases of acquired toxoplasmosis retinitis presenting in an outbreak. *Ophthalmology* 105(6):1032-7.

Cates SC, Carter-Young HL, Conley S, O'Brien B. 2004. Pregnant women and listeriosis: preferred educational messages and delivery mechanisms. *J Nutr Educ Behav* May-Jun;36(3):121-7.

CDC (U.S. Centers for Disease Control and Prevention). 2010. Preliminary FoodNet data on the incidence of infection with pathogens transmitted commonly through food --- 10 states, 2009. *Morbidity and Mortality Weekly Report (MMWR)*. Apr 16;59(14):418-422

Chapman B, Eversley T, Fillion K, MacLaurin T, Powell D. 2010. Assessment of food safety practices of food service food handlers (risk assessment data): testing a communication intervention (evaluation of tools). *Journal of Food Protection* 73:1101–1107.

Clark WF, Sontrop JM, Macnab JJ, Salvadori M, Moist L, Suri R, Garg AX. 2010. Long term risk for hypertension, renal impairment, and cardiovascular disease after gastroenteritis from drinking water contaminated with *Escherichia coli* O157:H7: a prospective cohort study. *BMJ* Nov 17:341:c6020. doi: 10.1136/bmj.c6020. PubMed PMID: 21084368.

Collins C, Green JA. A review of the pathophysiology and treatment of Shiga toxin producing *E. coli* infection. 2010. *Practical Gastroenterology* Apr;34(4):41-50.

Cooke RM and Shrader-Frechette K. 1991. Experts in uncertainty: opinion and subjective probability in science (Environmental Ethics and Science Policy). Oxford University Press.

CSPI (Center for Science in the Public Interest). 2009. Outbreak alert! Analyzing foodborne outbreaks 1998-2007. Center for Science in the Public Interest. *http://cspinet.org/new/pdf/outbreakalertreport09.pdf*

Delgado, AR. 2008. Listeriosis in pregnancy. *The Journal of Midwifery & Women's Health* 53: 255–259. doi: 10.1016/j.jmwh.2008.01.005

DeWaal CS, Hicks G, Barlow K, Alderton L, Vegosen L. 2006. Foods associated with foodborne illness out-

breaks from 1990 through 2003. *Food Protection Trends* 26(7):466-473.

Dubey JP, Jones JL. 2008. *Toxoplasma gondii* infection in humans and animals in the United States. Int *JParasitol* Sep;38(11):1257-78. PubMed PMID: 18508057.

Dubey JP. 2000. Sources of *Toxoplasma gondii* infection in pregnancy. Until rates of congenital toxoplasmosis fall, control measures are essential. *BMJ* Jul 15;321(7254):127-8. PubMed PMID: 10894674.

Dubey JP. 2009. Toxoplasmosis in pigs--the last 20 years. *Vet Parasitol* Oct 14;164(2-4):89-103. Epub May 23, 2009. PubMed PMID: 19559531.

Dubey JP. 2010. *Toxoplasma gondii* infections in chickens (Gallus domesticus): prevalence, clinical disease, diagnosis and public health significance. *Zoonoses Public Health* Feb;57(1):60-73. Epub Sep 10, 2009. PubMed PMID: 19744305.

Endrikat S, Gallagher D, Pouillot R, Hicks Quesenberry H, Labarre D, Schroeder CM, Kause J. 2010. A comparative risk assessment for *Listeria monocytogenes* in prepackaged versus retail-sliced deli meat. *J Food Prot* Apr;73(4):612-9. PubMed PMID: 20377948.

EPA (U.S. Environmental Protection Agency). 2010. Guidelines for Preparing Economic Analyses. EPA 240-R-10-001. National Center for Environmental Economics, Office of Policy. December. *http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Guidelines.html* Accessed March 11.

FDA (U.S. Food and Drug Administration). 2010a. Backgrounder: FDA Retail Food Safety Initiative. Washington, DC *http://www.fda.gov/Food/FoodSafety/RetailFoodProtection/FoodborneIllnessandRiskFactorReduction/RetailFoodRiskFactorStudies/ucm230315.htm*. Accessed March 22.

FDA (U.S. Food and Drug Administration). 2010b. FDA trend analysis report on the occurrence of foodborne illness risk factors in selected institutional foodservice, restaurant, and retail food store facility types (1998-2008). Washington, DC. *http://www.fda.gov/Food/FoodSafety/RetailFoodProtection/FoodborneIllnessandRiskFactorReduction/RetailFoodRiskFactorStudies/ucm223293.htm* Accessed March 22.

Frenzen PD, Drake A, Angulo FJ. 2005. Economic cost of illness due to *Escherichia coli* O157 infections in the United States. *J Food Prot* 68:2623-30.

Frenzen PD: 2008. Economic cost of Guillain-Barre syndrome in the United States. *Neurology* 71(1):21-7.

Friedman CR, Hoekstra RM, Samuel M, Marcus R, Bender J, Shiferaw B, Reddy S, Ahuja SD, Helfrick DL, Hardnett F, Carter M, Anderson B, Tauxe RV; Emerging Infections Program FoodNet Working Group. 2004. Risk factors for sporadic *Campylobacter* infection in the United States: a case-control study in FoodNet sites. *Clin Infect Dis* 38(S3): S285-S296 doi:10.1086/381598

GAO (U.S. Government Accountability Office). 1992. Food safety and quality: uniform, risk-based inspection system needed to ensure safe food supply. Report No. RCED-92-152. Washington, DC.

GAO (U.S. Government Accountability Office). 2001. Food safety and security–fundamental changes needed to ensure safe food. GAO-02-47T. Washington, DC. October 10.

GAO (U.S. Government Accountability Office). 2008 Food safety: improvements needed in FDA oversight of fresh produce. GAO-08-1047 September 26. *http://www.gao.gov/products/GAO-08-1047*

GAO (U.S. Government Accountability Office). 2011. Federal food safety oversight: food safety working group is a positive first step but governmentwide planning is needed to address fragmentation. GAO-11-289 March 18. *http://www.gao.gov/products/GAO-11-289*

Gombas, DE, Chen Y, Clavero RS, Scott VN. 2003. Survey of *Listeria monocytogenes* in ready-to-eat foods. *J Food Prot*. 66:559–569.

Gould LH, Demma L, Jones TF, Hurd S, Vugia DJ, Smith K, Shiferaw B, Segler S, Palmer A, Zansky S, Griffin PM. 2009. Hemolytic uremic syndrome and death in persons with *Escherichia coli* O157:H7 infection, Foodborne Diseases Active Surveillance Network sites, 2000–2006. *Clin Infect Dis* 49(10): 1480-1485 doi:10.1086/644621

Gradel, KO. Nielsen HL, Schønheyder HC, Ejlertsen T, Kristensen B, Nielsen H. 2009. Increased short- and long-term risk of inflammatory bowel disease after *Salmonella* or *Campylobacter* gastroenteritis. *Gastroenterology* Aug;137(2):495-501.

Greig JD, Ravel A. 2009. Analysis of foodborne outbreak data reported internationally for source attribution. *Int J Food Microbiol* Mar 31;130(2):77-87. PubMed PMID: 19178974.

Greig JD, Todd EC, Bartleson CA, Michaels BS. 2007. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 1. Description of the problem, methods, and agents involved. *J Food Prot* Jul;70(7):1752-61. PubMed PMID: 17685355.

Hanmer J, Lawrence WF, Anderson JP, Kaplan RM, Fryback DG. 2006. Report of nationally representative values for the noninstitutionalized US adult population for 7 health-related quality-of-life scores. *Med Decis Making* Jul-Aug;26(4):391-400. PubMed PMID: 16855127

Hennessy TW, Cheng LH, Kassenborg H, Ahuja SD, Mohle-Boetani J, Marcus R, Shiferaw B, Angulo FJ; Emerging Infections Program FoodNet Working Group. 2004. Egg consumption is the principal risk factor for sporadic *Salmonella* serotype Heidelberg infections: a case-control study in FoodNet sites. *Clin Infect Dis* 38(Suppl 3):237-43. doi:10.1086/381593

Hoffmann S, Fischbeck P, Krupnick A, and McWilliams M. 2007a. Elicitation from large, heterogeneous expert panels: using multiple uncertainty measures to characterize information quality for decision analysis. *Decision Analysis* 4(2):91-109.

Hoffmann S, Fischbeck P, Krupnick A, and McWilliams M. 2007b. Using expert elicitation to link foodborne illnesses in the U.S. to food. *Journal of Food Protection* 70(5):1220-11229.

Hoffmann S, Fischbeck P, Krupnick A, and McWilliams M. 2008. Informing risk-mitigation priorities using uncertainty measures derived from heterogeneous expert panels: a demonstration using foodborne pathogens. *Reliability Engineering and System Safety* 93(5): 687-698.

Hughes JM, Wilson ME, Johnson KE. Thorpe CM, Sears CL. 2006. The emerging clinical importance of non-O157 Shiga toxin-producing *Escherichia coli*. *Clin Infect Dis* 43(12): 1587-1595 doi:10.1086/509573

IOM (Institute of Medicine). 2006. Valuing health for regulatory cost-effectiveness analysis. Washington, DC: The National Academies Press.

Jackson KA, Iwamoto M, Swerdlow D. Pregnancy-associated listeriosis. 2010. *Epidemiology and Infection* 138:1503-1509. doi:10.1017/S0950268810000294

Jacob CJ, Powell DA. 2009. Where does foodborne illness happen-in the home, at foodservice, or elsewhere-and does it matter? *Foodborne Pathogens and Disease* Nov;6(9): 1121-1123. doi:10.1089/fpd.2008.0256

Jones JL, Dargelas V, Roberts J, Press C, Remington JS, Montoya JG. 2009. Risk factors for *Toxoplasma gondii* infection in the United States. *Clin Infect Dis* Sep 15;49(6):878-84. PubMed PMID: 19663709.

Jones JL, Dubey JP. 2010. Waterborne toxoplasmosis--recent developments. *Exp Parasitol* Jan;124(1):10-25. Epub 2009 Mar 24. PubMed PMID: 19324041.

Jones JL, Krueger A, Schulkin J, Schantz PM. 2010. Toxoplasmosis prevention and testing in pregnancy, survey of obstetrician-gynaecologists. *Zoonoses and Public Health* 57(1):27–33.

Jones TF, Angulo FJ. 2006. Eating in restaurants: a risk factor for foodborne disease? *Clin Infect Dis* 43(10):

1324-1328 doi:10.1086/508540

Kassenborg HD, Hedberg CW, Hoekstra M, Evans MC, Chin AE, Marcus R, Vugia DJ, Smith K, Ahuja SD, Slutsker L, Griffin PM; Emerging Infections Program FoodNet Working Group. 2004. Farm visits and undercooked hamburgers as major risk factors for sporadic *Escherichia coli* O157:H7 infection: data from a case-control study in 5 FoodNet sites. *Clin Infect Dis* 38(Supplement 3): S271-S278 doi:10.1086/381596

Kimura AC, Reddy V, Marcus R, Cieslak PR, Mohle-Boetani JC, Kassenborg HD, Segler SD, Hardnett FP, Barrett T, Swerdlow DL; Emerging Infections Program FoodNet Working Group. 2004. Chicken consumption is a newly identified risk factor for sporadic Salmonella enterica serotype Enteritidis infections in the United States: a case-control study in FoodNet sites. *Clin Infect Dis* Apr 15;38 Suppl 3:S244-52.

Leddy MA, Gonik B, Schulkin J. 2010. Obstetrician-gynecologists and perinatal infections: a review of studies of the Collaborative Ambulatory Research Network (2005-2009). *Infect Dis Obstet Gynecol* Vol 2010; Article ID 583950. 7p. Epub Nov 11.

Lynch MF, Tauxe RV, Hedberg CW. 2009. The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. *Epidemiology and Infection* 137:307-315.

MacDonald PD, Whitwam RE, Boggs JD, MacCormack JN, Anderson KL, Reardon JW, Saah JR, Graves LM, Hunter SB, Sobel J. 2005. Outbreak of listeriosis among Mexican immigrants as a result of consumption of illicitly produced Mexican-style cheese. *Clin Infect Dis* 40(5): 677-682 doi:10.1086/427803

Maki DG. 2009. Coming to grips with foodborne infection – peanut butter, peppers, and nationwide *Salmonella* outbreaks. *N Engl J Med* 360(10):949-53. Mar 5.

Mead PS, Slutsker L, Dietz V, McCaig LF, Bresee JS, Shapiro C, Griffin PM, Tauxe RV. 1999. Food-related illness and death in the References

Morgan GM, Henrion M. 1990. Uncertainty: a guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge, UK: Cambridge University Press.

Morgan K. 2011. U.S. Food and Drug Administration. Personal communication. March 8.

NAS (National Academies of Science). 1998. Ensuring safe food: from production to consumption. Institute of Medicine and National Research Council. Washington, DC: National Academy Press.

NAS (National Academies of Science). 2003. Scientific criteria to ensure safe food. Institute of Medicine and National Research Council. Washington, DC: National Academy Press. May.

NAS (National Academies of Science). 2010. Enhancing food safety: the role of the Food and Drug Administration. Institute of Medicine and National Research Council. Washington, DC: National Academy Press. June.

Ogunmodede F, Jones JL, Scheftel J, Kirkland E, Schulkin J, Lynfield R. 2005. Listeriosis prevention knowledge among pregnant women in the USA. *Infect Dis Obstet Gynecol* Mar;13(1):11-5.

OMB (U.S. Office of Management and Budget). 2003. Circular A-4, Re: regulatory analysis. Executive Branch, Washington, DC. Sept. 17. *http://www.whitehouse.gov/omb/circulars_a004_a-4/* (accessed March 11, 2011).

Osterholm MT. 2011. Foodborne disease in 2011 – The rest of the story. *N Engl J Med* Mar 10;364:10.

Painter JA, Ayers T, Woodruff R, Blanton E, Perez N, Hoekstra RM, Griffin PM, Braden C. 2009. Recipes for foodborne outbreaks: a scheme for categorizing and grouping implicated foods. *Foodborne Pathog Dis* Dec;6(10):1259-64. PubMed PMID: 19968563.

Pennington H. 2010. *Escherichia coli* O157. *The Lancet* Oct 23;*376*(9750):1428-1435. DOI: 10.1016/S0140-6736(10)60963-4.

Pires SM, Evers EG, van Pelt W, Ayers T, Scallan E, Angulo FJ, Havelaar A, Hald T; Med-Vet-Net Workpackage 28 Working Group. 2009. Attributing the human disease burden of foodborne infections to specific sources. *Foodborne Pathog Dis* May;6(4):417-24. PubMed PMID: 19415971.

Poropatich KO, Walker CL, Black RE. 2010. Quantifying the association between *Campylobacter* infection and Guillain-Barré syndrome: a systematic review. *J Health Popul Nutr* Dec;28(6):545-52.

Powell DA, Jacob CJ, Chapman BJ. 2011. Enhancing food safety culture to reduce rates of foodborne illness. *Food Control* Jun 22(6): 817-822. Epub Dec 24, 2010. DOI:10.1016/j.foodcont.2010.12.009.

Quiroz, ES, C. Bern, et al. 2000. An outbreak of cryptosporidiosis linked to a foodhandler. *J Infect Dis* 181(2): 695-700.

Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson MA, Roy SL, Jones JL, Griffin PM. 2011a. Foodborne illness acquired in the United States – major pathogens. *Emerg Infect Dis* 17:7-15

Scallan E, Griffin PM, Angulo FJ, Tauxe RV, Hoekstra RM. 2011b. Foodborne illness acquired in the United States – unspecified agents. *Emerg Infect Dis* 17:16-22

Shaw JW, Johnson JA, Coons SJ. US valuation of the EQ-5D health states: development and testing of the D1 valuation model. *Med Care*. 2005;43:203–20.

Suri RS, Mahon JL, Clark WF, Moist LM, Salvadori M, Garg AX. 2009. Relationship between *Escherichia coli* O157:H7 and diabetes mellitus. *Kidney Int Suppl* Feb;(112):S44-6. PubMed PMID: 19180134.

USDA (U.S. Department of Agriculture). 2009. New performance standards for *Salmonella* and *Campylobacter* in young chicken and turkey slaughter establishments: response to comments and announcement of implementation schedule. Food Safety and Inspection Service. Washington, DC. *http://www.fsis.usda.gov/OPPDE/rdad/FRPubs/2009-0029.pdf*

USDA (U.S. Department of Agriculture). 2010. The FSIS microbiological testing program for ready-to-eat (RTE) meat and poultry products, 1990–2009. Food Safety and Inspection Service. Washington, DC. *http://www.fsis.usda.gov/Science/Micro_Testing_RTE/* Last edited September 13, 2010. Accessed December 15, 2010.

USDA (U.S. Department of Agriculture). 2011. Potential public health impact of Salmonella and Campylobater performance guidance for young chickens and turkeys. Food Safety and Inspection Service, Washington, DC. *http://www.fsis.usda.gov/PDF/Potential_Public_Health_Impact_Sal_Campy_Performance_Guidance_Broilers_Turkeys_2011.pdf* Accessed March 22, 2011.

Varma JK, Samuel MC, Marcus R, Hoekstra RM, Medus C, Segler S, Anderson BJ, Jones TF, Shiferaw B, Haubert N, Megginson M, McCarthy PV, Graves L, Gilder TV, Angulo FJ. 2007. *Listeria monocytogenes* infection from foods prepared in a commercial establishment: a case-control study of potential sources of sporadic illness in the United States. *Clin Infect Dis* 44(4): 521-528 doi:10.1086/509920

Viscusi, WK. 1993. The Value of Risks to Life and Health. *Journal of Economic Literature* (31): 1912-46.

Voetsch AC, Angulo FJ, Jones TF, Moore MR, Nadon C, McCarthy P, Shiferaw B, Megginson MB, Hurd S, Anderson BJ, Cronquist A, Vugia DJ, Medus C, Segler S, Graves LM, Hoekstra RM, Griffin PM; Centers for Disease Control and Prevention Emerging Infections Program Foodborne Diseases Active Surveillance Network Working Group. 2007. Reduction in the incidence of invasive listeriosis in foodborne diseases active surveillance network sites, 1996-2003. *Clin Infect Dis* Feb 15;44(4):513-20.

Voetsch AC, Poole C, Hedberg CW, Hoekstra RM, Ryder RW, Weber DJ, Angulo FJ. 2009. Analysis of the FoodNet case-control study of sporadic *Salmonella* serotype Enteritidis infections using persons infected with other *Salmonella* serotypes as the comparison group. *Epidemiol Infect* Mar;137(3):408-16. doi:10.1017/S0950268808000897

Walker J, Nokes DJ, Jennings R. 1992. Longitudinal study of *Toxoplasma* seroprevalence in South Yorkshire. *Epidemiol Infect* Feb;108(1):99-106.

Welton, NJ, Ades, AE. 2005. A model of toxoplasmosis incidence in the UK: evidence synthesis and consistency of evidence. *JRSS (C) Applied Statistics* 54:385.

Wong S, Marcus R, Hawkins M, Shallow S, McCombs KG, Swanson E, Anderson B, Shiferaw B, Garman R, Noonan K, Van Gilder T; Emerging Infections Program FoodNet Working Group. 2004. Physicians as food-safety educators: a practices and perceptions study. *Clin Infect Dis* 38(Supplement 3): S212-S218 doi:10.1086/381589

APPENDICES A&B

APPENDIX A: RANKINGS OF TOP 50 PATHOGEN-FOOD COMBINATIONS

Table A-1: Top 50 pathogen-food combinations, by Combined QALY/$ Rank*

Rank	Pathogen-Food Combinations	QALY Loss	Cost of illness ($ mil.)	Illnesses	Hospital-izations	Deaths
1	*Campylobacter* - Poultry	9,541	1,257	608,231	6,091	55
2	*Toxoplasma* - Pork	4,495	1,219	35,537	1,815	134
3	*L. monocytogenes* - Deli Meats	3,948	1,086	651	595	104
4	*Salmonella* - Poultry	3,610	712	221,045	4,159	81
5	*L. monocytogenes* - Dairy	2,632	724	434	397	70
6	*Salmonella* - Complex foods	3,195	630	195,655	3,682	72
7	Norovirus - Complex foods	2,294	914	2,494,222	6,696	68
8	*Salmonella* - Produce	2,781	548	170,264	3,204	63
9	*Toxoplasma* - Beef	2,541	689	20,086	1,026	76
10	*Salmonella* - Eggs	1,878	370	115,003	2,164	42
11	*L. monocytogenes* - Complex foods	1,316	362	217	198	35
12	*Salmonella* - Beef	1,073	212	65,716	1,237	24
13	*Salmonella* - Pork	1,073	212	65,716	1,237	24
14	Norovirus - Produce	779	311	847,184	2,274	23
15	*Salmonella* - Dairy	1,000	197	61,235	1,152	23
16	*Yersinia* - Pork	1,013	180	69,889	381	21
17	*Toxoplasma* - Produce	772	209	6,104	312	23
18	*Salmonella* - Seafood	854	168	52,274	984	19
19	*Campylobacter* - Dairy	1,034	136	65,886	660	6
20	*Vibrio vulnificus* - Seafood	541	282	93	90	35
21	*E.coli* 0157 - Beef	828	144	33,410	1,131	11
22	Norovirus - Seafood	461	184	501,684	1,347	14
23	*Salmonella* - Breads and Bakery	585	115	35,845	675	13
24	*L. monocytogenes* - Pork	439	121	72	66	12
25	*L. monocytogenes* - Poultry	439	121	72	66	12

Table A-1 (continued): Top 50 Pathogen-Food Pairs, By Combined QALY/$ Rank*

Rank	Pathogen-Food Pair	QALY Loss	Cost of illness ($ mil.)	Illnesses	Hospital-izations	Deaths
26	*L. monocytogenes* - Produce	439	121	72	66	12
27	*L. monocytogenes* - Seafood	439	121	72	66	12
28	*Campylobacter* - Produce	693	91	44,178	442	4
29	Norovirus - Breads and Bakery	392	156	425,958	1,144	12
30	*Salmonella* - Deli/Other Meats	561	111	34,352	646	13
31	Norovirus - Poultry	387	154	421,225	1,131	11
32	*Campylobacter* - Pork	584	77	37,215	373	3
33	*Campylobacter* - Beef	580	76	36,952	370	3
34	*Toxoplasma* - Poultry	410	111	3,242	166	12
35	*C. perfringens* - Beef	285	101	314,612	143	8
36	*C. perfringens* - Poultry	234	83	258,080	117	7
37	*Toxoplasma* - Dairy	261	71	2,062	105	8
38	Norovirus - Beef	205	82	222,445	597	6
39	*C. perfringens* - Complex foods	212	75	233,501	106	6
40	*Campylobacter* - Eggs	341	45	21,749	218	2
41	*E.coli* 0157 - Produce	283	49	11,408	386	4
42	*Shigella* - Complex foods	245	54	58,930	654	4
43	*Toxoplasma* - Deli/Other Meats	188	51	1,490	76	6
44	Norovirus - Pork	144	57	156,185	419	4
45	*E.coli* 0157 - Complex foods	232	40	9,371	317	3
46	Norovirus - Deli/Other Meats	113	45	123,055	330	3
47	*Cryptosporidium* - Produce	203	28	34,286	125	2
48	*Yersinia* - Dairy	173	31	11,917	65	4
49	*Salmonella* - Beverages	171	34	10,455	197	4
50	Norovirus - Dairy	109	43	118,322	318	3

* Excluding pathogens in game

Figure A-1: Top 20 Pathogen Food Combinations

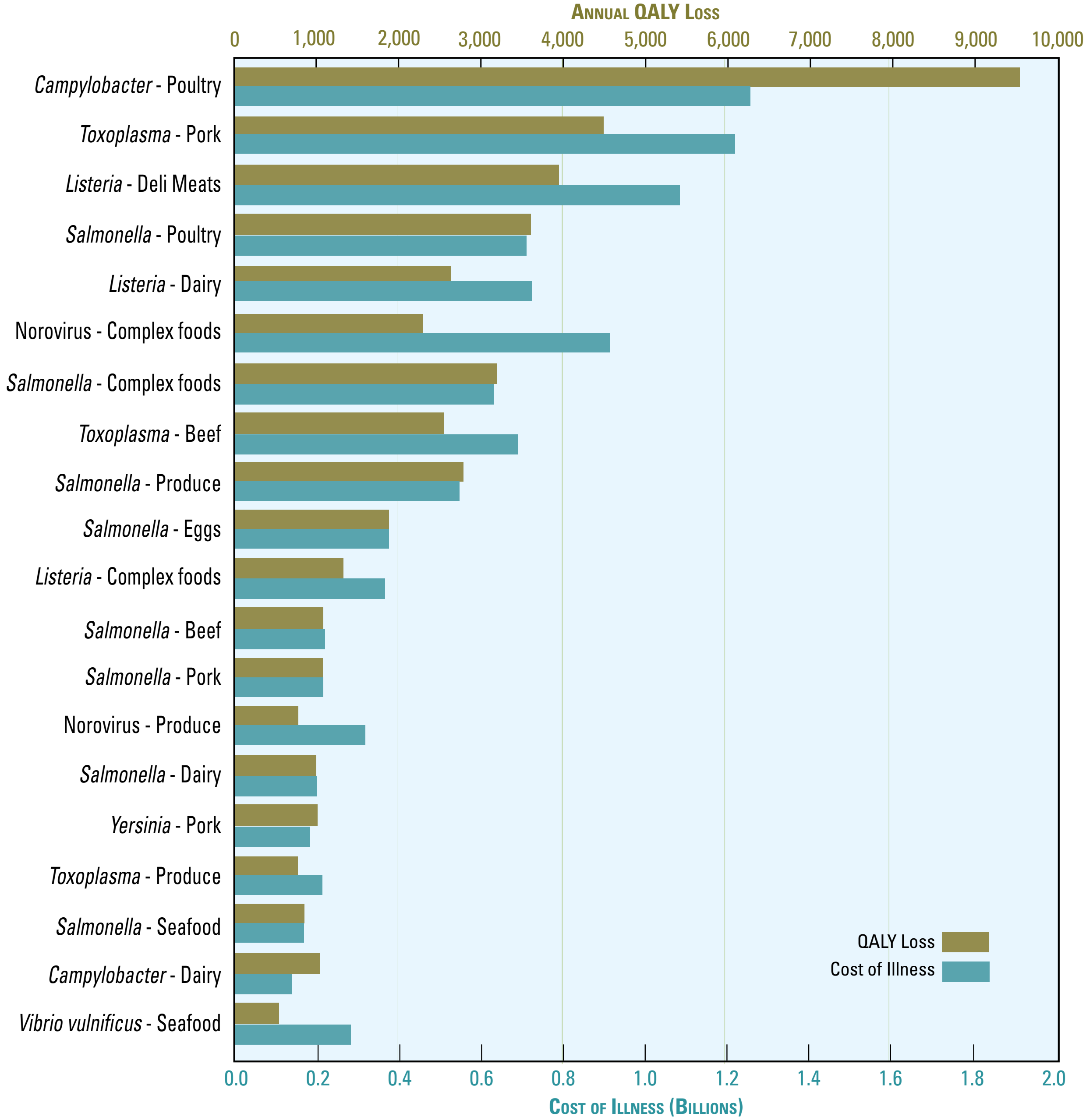
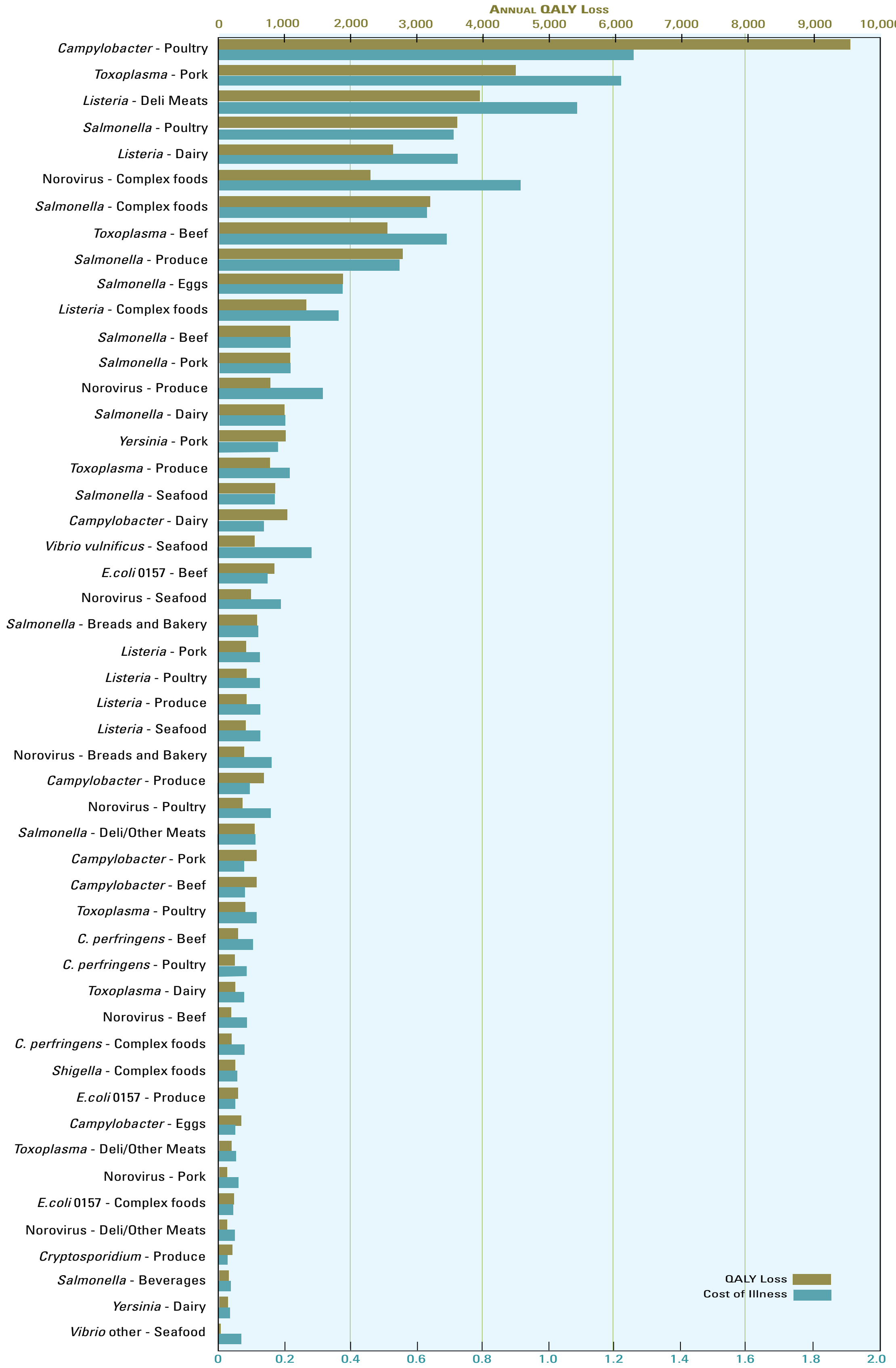


Figure A-2: Top 50 Pathogen-Food Combinations By Cost Of Illness And By QALY Loss, Ordered By Combined Rank



APPENDIX B: ATTRIBUTION DATA

This appendix includes some information on the data used to estimate attributable fractions for each pathogen.

Tables E-1 and E-2 show the number of outbreaks and outbreak cases which we binned into each food category, based on CDC summary line-listing data from 1998-2008.

We created rules for how to bin specific foods identified in outbreaks. For many outbreaks, this binning was straightforward. If "ground beef" was identified in the outbreak investigation, we binned it under "Beef." But other dishes require some judgment. For example, meat dishes – in which meat is the primary but not only ingredient – were binned with meats. "Complex dishes" captures those non-meat dishes with multiple ingredients, where the contaminated ingredient could not be identified; such foods include pasta dishes, pizza, rice dishes, deli salads, green salads (which often include cheese, dressings, and other non-produce ingredients), sauces, sandwiches, processed foods such as peanut butter and miscellaneous take-out dishes. Sometimes the outbreak investigations simply identify "ethnic food." The "Multi-Source" category is relevant to bin those outbreaks for which multiple dishes, meat and non-meat, were identified as potential vectors; in such cases, we felt it would be a mistake to attempt to attribute these either to meats or to the non-meat (e.g. produce, eggs, complex foods), so we dropped them from the analysis.

Table B-1: Foodborne Outbreaks, By Food Category, 1998-2008

	Campylobacter spp.	*Clostridium perfringens*	*Cryptosporidium parvum*	*Cyclospora cayetanensis*	*E. coli* O157:H7	*E. coli*, non-O157 STEC	*Listeria monocytogenes*	Norovirus	*Salmonella* nontyphoidal	*Shigella* spp.	*Vibrio* spp.	*Yersinia enterocolitica*
Beef	7	128	0	0	82	6	0	47	44	6	0	0
Beverages	0	0	2	0	3	2	0	24	7	0	0	0
Bread and baked goods	0	0	0	0	1	0	0	90	24	0	0	0
Dairy products	63	2	0	0	10	3	6	25	41	1	0	0
Eggs	0	0	0	0	0	0	0	7	77	0	0	0
Game	2	1	0	0	0	0	0	1	0	0	0	0
Deli/Other Meats	2	11	0	0	6	0	5	22	19	2	0	1
Complex foods	14	95	2	3	23	1	3	527	131	22	0	0
Multi-Source	16	115	0	2	15	3	1	358	124	12	0	1
Pork	3	34	0	0	0	0	1	33	44	0	0	5
Poultry	25	105	0	0	1	1	4	92	152	6	1	0
Produce	8	13	0	11	28	2	1	179	114	8	0	0
Seafood	5	4	0	0	1	0	1	106	35	4	75	0
Unknown	66	79	13	8	88	21	4	1938	476	67	3	2
Total	211	587	17	24	258	39	26	3449	1288	128	79	9
Total attributable	129	393	4	14	155	15	21	1153	688	49	76	6

Note: Total attributable excludes unknown and multi-source outbreaks. There were zero outbreaks reported due to *Toxoplasma gondii.*

Table B-2: Foodborne Outbreak Cases, By Food Category, 1998-2008

	Campylobacter spp.	*Clostridium perfringens*	*Cryptosporidium parvum*	*Cyclospora cayetanensis*	*E. coli* O157:H7	*E. coli*, non-O157 STEC	*Listeria monocytogenes*	Norovirus	*Salmonella* nontyphoidal	*Shigella* spp.	*Vibrio* spp.	*Yersinia enterocolitica*
Beef	241	4219	0	0	1556	91	0	628	949	91	0	0
Beverages	0	0	356	0	39	230	0	727	752	0	0	0
Bread & baked goods	0	0	0	0	29	0	0	2536	1041	0	0	0
Dairy products	2746	47	0	0	110	351	52	819	1273	2	0	0
Eggs	0	0	0	0	0	0	0	116	1937	0	0	0
Game	4	5	0	0	0	0	0	17	0	0	0	0
Deli/other meats	25	442	0	0	107	0	125	634	464	102	0	9
Complex foods	128	2581	13	35	579	3	86	16966	4772	999	0	0
Multi-Source	457	5595	0	172	300	74	2	11215	5641	214	0	5
Pork	78	868	0	0	0	0	3	779	1070	0	0	59
Poultry	193	4206	0	0	36	2	99	2079	3307	354	47	0
Produce	513	1313	0	954	1564	26	6	5928	7287	2020	0	0
Seafood	280	31	0	0	14	0	5	2024	645	61	1161	0
Unknown	795	2139	219	162	1008	777	17	57061	8376	2563	9	18
Total	5460	21446	588	1323	5342	1554	395	101529	37514	6406	1217	91
Total attributable	4208	13712	369	989	4034	703	376	33253	23497	3629	1208	68

Note: Total attributable excludes unknown and multi-source outbreaks. There were zero outbreaks reported due to *Toxoplasma gondii*.

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Design and layout: Office of Research, University of Florida, Gainesville, Florida.
Editing: Burness Communications, Bethesda, Maryland.
Fonts used: Berthold Akzidenz Grotesk, Univers Condensed.

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